THE

SCENERY OF SWITZERLAND

THE GLACIER OF THE RHONE.

THE SCENERY

OF

ITZERLAND

AND

HE CAUSES TO WHICH IT IS DUE

BY

THE RIGHT HON.

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PREFACE

In the summer of 1861 I had the pleasure of spending a short holiday in Switzerland with Huxley and Tyndall. Tyndall and I ascended the Galenstock, and started with Benen, who afterwards lost his life on the Haut de Cry, up the Jungfrau, but were stopped by an accident to one of our porters, who fell into a deep crevasse, from which we had some difficulty in extricating him, as Tyndall has graphically described in his *Hours of Exercise on the Alps.*

From that day to this many of my holidays have been spent in the Alps. On them I have enjoyed many and many delightful days; to them I owe much health and happiness, nor must I omit to express my gratitude to the Swiss people for their kindness and courtesy.

My attention was from the first directed to the interesting problems presented by the physical geography of the country. I longed to know what forces had raised the mountains, had hollowed out the lakes, and directed the rivers. During all my holidays these questions have occupied my thoughts, and I have read much of what has been written about them. Our knowledge is indeed very incomplete, many problems still baffle the greatest Geographers, as to others there is still much difference of opinion. Nevertheless an immense fund of information has been gathered together; on many points there is a fair concensus of opinion amongst those best qualified to judge, and even where great authorities differ a short statement of their views, in a form which might be useful to those travelling in Switzerland, could hardly fail to be interesting and instructive. No such book is, however, in existence. I urged Tyndall and several others far better qualified than I am myself, to give us such a volume, feeling sure that it would be welcome to our countrymen, and add both to the pleasure and to the interest of their Swiss trips. They were all, however, otherwise occupied, but they encouraged me to attempt it, promising me their valuable assistance, and this must be my excuse for undertaking the task, perhaps prematurely. Tyndall we have unfortunately lost, but Professor Heim and Sir John Evans have been kind enough to take the trouble of looking through the proofs, and I am indebted to them for many valuable suggestions.

The Swiss Government have published a series of excellent maps, which has been prepared at the cost of the State, under the general direction of General Dufour. There is also a geological map by Studer and Escher, which was admirable at the time it appeared, and has in the main stood the test of more recent researches. Studer was in fact the father of Swiss Geology; he accumulated an immense amount of information which has been most useful to subsequent authors, and if I have not quoted his researches more often, it is because I have been anxious to give the latest authorities. In 1858 he suggested that the Dufour map should be taken as the basis of a geological survey on a larger scale. To this the Swiss Government assented; they voted the modest sum of £120, since increased to £400 a year, and appointed a Commission, consisting of Messrs. B. Studer, P. Mirian, A. Escher von der Linth, A. Favre, and E. Desor. Under their supervision the present geological map, in twenty-five sheets, has gradually appeared: the last being published in 1888, on the very day of Studer's death.

In addition to the geological maps themselves, the Commission have published a splendid series of descriptive volumes, over thirty in number, by A. Müller, Jaccard, Greppin, Möesch, Kaufmann, Escher, Theobald, Gilliéron, Baltzer, Fritsch, Du Pasquier, Burckhardt, Quereau, Heim, Schmidt, Favre, Renevier, Gerlach, Schardt, Fellenberg, Rolle, Taramelli, and others.

This is not the place to catalogue the separate Volumes and Memoirs on Swiss Geology and Physical Geography. Jaccard[1] in his work on the Jura and Central Switzerland enumerates no less than 959, but among the most important I may mention Heim's magnificent work, *Mechanismus der Gebirgsbildung*, Studer's *Geologie der Schweiz*, Agassiz's *Études sur les Glaciers*, Suess's *Das Antlitz der Erde*, Favre's *Recherches Geologiques;* for the fossils that of Heer; and among

[1] L. vii. Sup. 2.

shorter publications, in addition to those by the geologists already referred to, especially those of Bonney, Morlot, Penck, Ramsay, Rütimeyer, and Tyndall.

I have dwelt specially on the valleys of the Arve, Rhone and Rhine, the Reuss, Aar, Limmat and Ticino as types of longitudinal and cross valleys; and because they are among the districts most frequently visited. They have, moreover, been admirably described, especially by Favre, Heim, Renevier and Rütimeyer.

I am fully conscious of the imperfections of this book: no doubt by waiting longer it might have been made better; but I should have felt the same then also, and in the words of Favre, "il n'y a que ceux qui ne font rien qui ne se trompent pas."[1]

[1] *Rech. Geol.* iii. 76.

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LIST OF STRATA

		Principal Swiss Representatives.
Recent		
Post-Tertiary		Glacial and Interglacial deposits
Tertiary	Pliocene	
	Miocene	Mollasse and Nagelflue
	Eocene	Nummulitic Limestone and Flysch
Secondary	Cretaceous	Cenomanian (Seewenkalk) Gault Schrattenkalk, Urgonian, and Aptian Neocomian Valangian
	Jurassic	Malm (Hochgebirgskalk) Dogger Lias
	Trias	Keuper Muschelkalk. Haupt Dolomite Bunter Sandstein
Palæozoic	Permian	Verrucano
	Carboniferous	Puddingstones, Slates, and Sandstone
	Devonian ? Silurian ? Cambrian ?	Various Crystalline Schists Eruptive Rocks
Crystalline Schists Gneiss, etc.		

GLOSSARY

Anchitherium. An Eocene quadruped, intermediate between the Tapirs and the Equida. They are regarded as ancestors of the Horse.

Anticlinal, see p. 43.

Archæan. The Geological Record may be classified in 5 divisions—1, Archæan; 2, Palæozoic (Ancient Life); 3, Secondary or Mesozoic (Middle Life); 4, Tertiary; and 5, Quaternary.

Argillaceous Rock. Consisting of, or containing, clay.

Batrachia. The group of animals to which Frogs, Toads, and Newts belong.

Belemnites. Cephalopods; allied to the Squid and Cuttlefish.

Bergschrund, see p. 75.

Bündnerschiefer, see p. 13.

Bunter, see p. 10.

Carboniferous, see p. 8.

Cargneule. A rock belonging to the Triassic period.

Cleavage, see p. 53.

Crevasses, see p. 87.

Deckenschotter, see p. 132.

Dinotherium. A gigantic Mammal belonging to the Miocene period.

Diorite. A rock differing from granite in containing less Silica.

Dip, see p. 41.

Dogger, see p. 13.

Dolomite. Magnesian Limestone.

Eocene, see p. 17.

Erratics, see p. 18.

Eyed-Gneiss, see p. 4.

Felspar. Constitutes the largest portion of Plutonic and Volcanic rocks; anhydrous, aluminous, and magnesian Silicates.

Firn, see p. 75.

Flysch, see p. 18.

Fold Fault, see p. 43.

Foraminifers. A group of microscopic shells.

Gabbro, see p. 4. A group of coarsely crystalline rocks.

Gault, see p. 16.

Geotectonic, see p. 137.

Glacier-Grain, see p. 81.

Gneiss, see p. 2.

Granite, see p. 5.

Hauptdolomite, see p. 11.

Hochgebirgskalk, see p. 14.

Hornblende. A group of Silicates, so called from their horn-like cleavage, and peculiar lustre.

Horst, see p. 30.

Keuper, see p. 10.

Lias, see p. 12.

Lœss, see p. 109.

Magma, see p. 4.

Malm, see p. 14.

Mastodon. A gigantic quadruped, allied to the Elephant.

Mesozoic, see under *Archæan*.

Miocene, see p. 19.

Mollasse, see p. 19.

Monoclinal Fold, see p. 41.

Moraine, see p. 95.

Muschelkalk, see p. 10.

Nagelfluc, see p. 19.

Neocomian, see p. 15.

Névé, see p. 75.

Nummulites, see p. 17.

Orthoclase. An original constituent of many crystalline rocks, including Granite, Gneiss, Syenite, etc.

Outcrop, see p. 41.

Palæotherium. A Tapir-like Mammal, belonging to the Eocene period.

Palæozoic, see under *Archæan*.

Permian, see p. 10.

Plagioclase. A kind of Felspar. Tschermak characterises it as a mixture of Soda Felspar and Lime Felspar.

Plutonic. Igneous rocks which have consolidated below the surface.

Porphyry, see p. 5.

Protogine, see p. 5.

Quartz. A form of Silica.

Regelation, see p. 85.

Schist. A rock which is split up into thin irregular plates.

Secondary, see under *Archæan.*

Seewen-Limestone, see p. 16.

Sericite. A talc-like variety of Mica.

Serpentine, see p. 6.

Slickensides, see p. 49.

Strike, see p. 41.

Synclinal, see p. 43.

Trias, see p. 10.

Urgonian, see p. 15.

Valangian, see p. 15.

Verrucano, see p. 9.

CHAPTER I

THE GEOLOGY OF SWITZERLAND

Vidi ego, quod fuerat quondam solidissima tellus,
Esse fretum: vidi factas ex æquore terras;
Et procul a pelago conchæ jacuere marinæ.
OVID, *Metam.* xv. 262.

Straits have I seen that cover now
What erst was solid earth; have trodden land
Where once was sea; and gathered inland far
Dry ocean shells.
Ovid's Metam., trans. by H. KING.

THE Scenery of Switzerland is so greatly due to geological causes, that it is impossible to discuss the present configuration of the surface, without some reference to its history in bygone times. I do not, however, propose to deal with geology further than is necessary for my present purpose.

The subject presents very great difficulties, not only because the higher regions are so much covered with snow, accessible only for a few weeks in the year, and in many places covered by accumulations of debris, but especially because the rocks have been subjected to such extremes of heat and pressure that not only have the fossils been altered, and often entirely destroyed, but the very rocks themselves have been bent, folded, reversed, fractured, crushed, ground, and so completely metamorphosed that in many cases their whole character has been changed beyond recognition.

Igneous Rocks—Gneiss

To commence with the Igneous series, Gneiss, which is in Switzerland as elsewhere the fundamental rock, forms in great part the central ranges, reappearing also here and there in other parts, as for instance on the Rhine at Laufen, and would, it is thought, be found everywhere if we could penetrate deep enough.

Gneiss is composed of Quartz, Felspar, and Mica, with a more or less foliated structure. The Felspar is generally white, but sometimes green or pink, and has often a waxy lustre; the Mica is white, brown, or black. The Quartz forms a sort of paste wrapping round the other ingredients.

Gneiss presents the same general characters all over the world. It is not all of the same age, and if some is comparatively recent, at any rate the oldest rock we know is Gneiss. This gives it a peculiar interest. The foliation of Gneiss is probably of two kinds: the one due to pressure, crushing, and shearing of an original igneous rock such as Granite, the other to original segregation-structure.[1]

"Gneiss," says Bonney, "may be, if not actually part of the primitive crust of the earth, masses extruded at a time when molten rock could be reached everywhere near to the surface, and when the process of cooling, even at a very moderate depth, was much slower than it became in the ages after the earth had begun to be occupied by living creatures."[2]

The original crust indeed, if we use the words in their popular sense to mean the superficial layers, was probably more like basalt, or the lavas of our existing volcanoes. Gneiss, on the other hand, must have cooled and solidified under considerable pressure and at a great depth. When we stand on a bare surface of Gneiss we must remember—and it is interesting to recollect—that it must have been originally covered by several thousand feet of rock, all of which have been removed.

"Probably," says Geikie, "the great majority of geologists now adopt in some form the opinion, that the oldest or so-called

[1] Heim, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.; Geikie, *Text-book of Geology*.

[2] *Story of our Planet.*

'Archæan' Gneisses are essentially eruptive rocks. . . . Whether they were portions of an original molten 'magma' protruded from beneath the crust or were produced by a re-fusion of already solidified parts of that crust or of ancient *sedimentary* accumulations laid down upon it, must be matter of speculation."[1]

On the other hand, Gneiss is certainly not all of the same age, being in some instances comparatively modern, since it traverses other strata. There are, moreover, cases in which *sedimentary* strata have been metamorphosed by heat or pressure into a rock which cannot mineralogically be distinguished from Gneiss.

Gneiss presents many varieties. The principal are Granite-gneiss, where the schistose arrangement is so coarse as to be unrecognisable, save in a large mass of the rock; Diorite-gneiss; Gabbro-gneiss, composed of the materials of a Diorite or Gabbro, but with a coarsely schistose structure; Porphyritic-gneiss or Eyed-gneiss, in which large eye-like kernels of Orthoclase or Quartz are dispersed through a finer matrix, and represent larger crystals or crystalline aggregates which have been broken down and dragged along by shearing movements in the rock.

[1] *Text-book of Geology.*

Granite

Granite, like Gneiss, is composed of Quartz, Mica, and Felspar, but differs from it in not being foliated.

Granite is a plutonic rock and may be of any age; it often sends veins into the surrounding strata, which it then forces out of position, in which case they show evidence as they approach it of being much altered by heat. It solidified at a considerable depth below the surface, and its upper portions probably flowed out as lava. It presents much variation: if it shows traces of foliation it is known as Gneiss-granite. Hornblende-granite contains Hornblende in addition to the other elements. Syenite consists of Felspar (Orthoclase) and Hornblende. Diorite differs in containing Plagioclase instead of Orthoclase, and less Silica; if the Felspar crystals are large and well defined, it is known in popular language as Porphyry. Protogine, so named because it was formerly supposed to be the oldest of all rocks, is a Granite, containing Sericite instead of ordinary Mica.

Granite, like Gneiss, must have solidified under considerable pressure, and therefore at a great depth. In the first place, the crystals it contains could not have been formed unless the process of cooling had been very slow.

In addition to this, Granite presents a great number of minute cavities containing water, liquefied carbonic acid, and other volatile substances. Sorby, whose main conclusions have since been verified by others, has endeavoured to calculate what must have been the pressure under which Granite solidified, by measuring the amount of contraction in the liquids which have been there imprisoned. He considered that the Granites which he examined must have consolidated at depths of from 30,000 to 50,000 feet. The more superficial layers probably resembled Basalt and Lava.

Serpentine

Serpentine is a compact or finely granular rock, olive-green, brown, yellow, or red, and has a more or less silky lustre. There has been much doubt as to its origin, but it is now regarded by many geologists as eruptive. This view is, however, by no means universally accepted, at least as applying to all Serpentines.

Crystalline Schists

Over the Gneiss lie immense masses of Crystalline Schists, several thousand feet in thickness. No fossils have been found in them, though the presence of Graphite and seams of Limestone have been supposed to indicate the existence of vegetable and animal life. The more ancient were perhaps deposited while the waters of the ocean were still at a high temperature. So generally distributed are these Schists, that in the opinion of many geologists they everywhere underlie the other stratified formations as a general platform or foundation. In parts of Switzerland, however, sedimentary strata have been so much modified by pressure, and in many cases by heat, that it is very difficult, and sometimes impossible, to distinguish them from the older Crystalline Schists. "At one end," says Geikie, "stand rocks which are unmistakably of sedimentary origin, for their original bedding can often be distinctly seen, and they also contain organic remains similar to those found in ordinary unaltered sedimentary strata. At the other end come coarsely crystalline masses, which in many respects resemble Granite, and the original character of which is not obvious. An apparently unbroken gradation can be traced between these extremes, and the whole series has been termed Metamorphic from the changed form in which its members are believed now to appear." The discovery of fossils has indeed proved that certain Schists are Silurian, others Devonian, Carboniferous, and even Jurassic, but no Swiss geologists consider that the Crystalline Schists of the Central "Massives" of the Alps are metamorphic Mesozoic rocks.[1] The Schists are generally intensely folded and crumpled. The presence of boulders of foliated Crystalline Schist in the Carboniferous Puddingstones, proves that the foliation was original, or at least anterior to the Coal period.[2]

The problems, however, presented by these rocks are, as Geikie says, so many and difficult that comparatively little progress has yet been made in their solution.

THE CARBONIFEROUS PERIOD

The earliest fossiliferous rocks in Switzerland belong to the Coal or Carboniferous period. The older Cambrian and Silurian rocks, which elsewhere present so rich a flora and fauna, and attain a thickness of many thousand feet, are perhaps represented in Switzerland by some of the Crystalline Schists, though this is not yet certainly proved.

A belt of Carboniferous strata extends from Dauphiné along the valley of the Isère and the Arve, presenting fossiliferous deposits at Brevent, Hüningen, etc. It then passes along the lower Valais, and, if the Verrucano belongs

[1] Heim, *Quart. Jour. Geol. Soc.* 1890.
[2] Lory, *Int. Geol. Cong.* 1888.

to this period, occupies a considerable part of the district between the Upper Rhine and the Walensee. It is clear, however, and this indeed applies to the fossiliferous strata generally, that these beds are only remnants of much more extensive deposits. In places they have been removed, and in others they have been deeply buried under more recent strata. At the same time much of Switzerland is supposed to have been land at this period, probably forming a large island, or islands, while the presence in the Valais and the Mont Blanc district of Puddingstone containing pebbles and boulders shows that there must have been some high land, and rapid streams. The Coal was probably formed in deposits somewhat similar to our peat-mosses.

The vegetation consisted principally of Ferns, Mosses, Clubmosses (Lycopodiacæ), and Equisetums. There appear to have been some flowering plants, but the blossoms were probably inconspicuous. Insects were represented by forms resembling the Cockroach, but there were no Bees, Flies, Butterflies, or Moths. Batrachia make their appearance, but there were no Mammals or Birds. The Verrucano, or, as it is often called, Sernifite, from the Sernfthal, is a sandy or pebbly deposit belonging either to the close of the Carboniferous or commencement of the Permian period.

Permian

During the Permian period also Switzerland was partly above the sea-level, partly covered by the sea. The land appears to have gradually sunk, commencing in the east, and in the

Triassic

period we find evidence of deep seas, which appear to have covered the whole area of Switzerland. The name "Trias" was given to it because in many districts, though not everywhere, it falls into three principal divisions, a brown, white, green, or reddish Sandstone, known as the Bunter Sandstein, the Muschelkalk or Shelly Limestone, and the Keuper, consisting of marls and limestones.

In Switzerland, as in England, there are considerable salt deposits belonging to this period. Another very characteristic rock of this age is Gypsum, and the Dolomites also belong to this period. Many mineral waters spring up from, and owe their properties to, the Triassic beds. The Keuper districts are generally rich, Dolomites on the contrary poor, desolate, and often almost without vegetation, but very beautiful from their richness of color, and rugged forms.

The Muschelkalk is often, as, for instance, on the Virgloria pass, a hard black limestone, splitting into thin slabs, which take a good polish and are used for tables.

The earliest Mammals appeared in this period.

To the Trias belongs a thick deposit of gray, whitish, or yellow Dolomite, sometimes compressed into Marble, which is known as Hauptdolomite, and, especially to the east of the Rhine, forms great mountain masses, often presenting the appearance of gigantic ruins. It is unfossiliferous.

The account here given of the geography of Switzerland in past times differs, as will be seen, considerably from that indicated in the maps to Heer's *Primæval World of Switzerland.* Prof. Heer regarded the present boundaries of the different formations as indicating their original extension. This however is certainly not the case. The Jurassic strata, for instance, were not deposited near any land. There are no shore animals nor pebbles, as there must have been if they were coast deposits.

Jurassic

The principal Jurassic strata in Switzerland are the Lias, the Dogger, and the Malm. They attain together a thickness of over 2500 feet. During this period Ammonites and Belemnites reached their fullest development, as also did the great Sea-reptiles, the Icthyosaurus and Plesiosaurus. At this period also flourished the flying reptiles or Pterodactyles, and we also meet the first bird (Archæopteryx), which differed from all existing species, by the possession of a long tail, and in other ways.

Lias

During this period the whole of Switzerland appears to have been covered by the sea. There must however have been land not far off, as remains of Beetles, Cockroaches, Grasshoppers, Termites, Dragon-flies, Bugs, and other Insects occur in the Lias of Schambelen, near the junction of the Reuss, the Aar, and the Limmat, and elsewhere. No Bees, Butterflies, or Moths have been met with.

It is probable that the Black Forest and the Vosges were dry land. The fossils, however, on the whole, indicate a deep sea. The Lias is gray or blackish, calcareous, sandy, or argillaceous stratum. The dark color is probably owing to the amount of organic matter which it contains. Heer suggests that the best explanation may be afforded by the *Sargasso Sea.* The Atlantic Ocean, for an area of about 40,000 square miles, is covered by Sargasso-weed so densely that ships sometimes find a difficulty in forcing their way through it. The sea is deep, and the fragments of dead weed are probably quite decayed before they reach the bottom, to which they would give a dark color. He thus explains the color of this limestone.

The "Bündner Schiefer" so largely developed in the Grisons and Valais are now considered, from the fossils which have been discovered in several places, to belong to this period.

Dogger or Brown Jura

Switzerland was for the most part under water at this period, but that there must have been land in the neighbourhood during some part of the time is proved by the existence, near Porrentruy, of beds containing several species of Limpets (Patella), Periwinkles (Purpura), Mussels (Mytilus), Neritas, and other shore molluscs. It is probable that the Black Forest and the Vosges were then dry land.

Malm, or Upper Jurassic

The Malm is characterised by a considerable development of Coral reefs, which often attained a great thickness. Between the Corals, which in some cases still retain their natural position, are many remains of Sea-urchins, Sponges, Molluscs, and some Crustacea, united by calcareous cement into a more or less solid rock.

They are often beautifully preserved, having been embedded in the soft mud of a quiet sea, which extended completely over the central Alps. Indeed the southern shore of the Jurassic Sea must, in Heim's opinion, be looked for in northern Africa.

The Malm is yellow and white in the Jura, blue-black in the Alps; by its hard, bare, steeply inclined rocks, and dry sterile slopes, it gives a special character to the landscape, while the Dogger, and still more the Lias, from their numerous marly layers, furnish a very fertile soil. Where Malm is a dark-bluish, gray, conchoidal, calcareous rock, it is known as "Hochgebirgskalk." In the celebrated deposits of Solenhofen many remains of *Insects* occur, including a Moth, the earliest Lepidopterous insect yet known.

Cretaceous

As in the Jurassic period, so also in the Cretaceous, Switzerland was under the sea. To the east, however, was dry land. The complete difference between the animals of the Malm or Upper Jurassic, and then of the Neocomian or Lower Cretaceous, appear to imply a change of conditions or great lapse of time. It was at one time supposed[1] that the southern shore of the Swiss Cretaceous Sea

[1] Heer, *Primæval World of Switzerland.*

followed a line drawn from the Walensee to Altorf, the Lake of Brienz and Bex, but though this is the present limit of the strata they once extended much farther, and have been removed by denudation. Heim considers that islands began to show themselves in the region of the Central Alps in Cretaceous times.

The Swiss Cretaceous strata fall into five principal divisions. The first or oldest—Valangian—consists of a dark hard silicious and sometimes oolitic limestone as on the Sentis, or of bluish gray marls and limestone as in the Jura.

The Neocomian, from the old name of Neuchâtel, is sometimes a dark gray or black hard marl, sometimes a bluish gray marl which easily disintegrates in the air, but contains beds of excellent stone of which Neuchâtel is built.

The Urgonian (so called after the town of Orgon, near Arles), or Schrattenkalk, is widely distributed in the Alps. It is a hard white limestone, the surface of which is often furrowed by innumerable channels, which form a perfect labyrinth. It stands in rocky walls often several hundred feet high, and from its great powers of resistance often forms the ridges and water-sheds. It is arid and barren, offering a great contrast to the Neocomian, which generally bears a luxuriant vegetation.

The Gault contains many dark green grains which are a silicate of protoxide of Iron. It forms the dark bands which are so conspicuous against the paler color of the other Cretaceous rocks.

The Seewen Limestone, so called from the village of Seewen on the Lake of Lowerz, corresponds to our Chalk, and like it consists mainly of microscopic shells. The eastern and western parts of Switzerland differ considerably in the species. The Cretaceous deposits being of marine origin we cannot expect to know much of the land animals or plants. The forests, however, contained Cycads and Conifers, Pines, Sequoias, etc., and Dicotyledonous trees now make their appearance, the earliest being a species resembling a poplar found in the Cretaceous beds of Greenland. In the upper Cretaceous strata Dicotyledons are more numerous, and it is interesting to find that they are mostly species in which the pollen is carried from flower to flower by the wind, or such as Magnolia, which are fertilised by beetles. Bees and Butterflies were still apparently absent or rare, and hence also the beautiful flowers specially adapted to them.

Eocene

At this period the formation of islands on the site of the present Alps appears to have commenced. The two principal rocks of the Eocene period are the Nummulitic Limestone and the Flysch. They represent differences of condition rather than of time. Bands of Nummulitic Limestone often occur in the Flysch, showing that for a while the sea was favourable for the development of Nummulites. Then the conditions changed, and they disappeared. This happened again and again.

Nummulitic Limestone

The Nummulitic Limestone is so called because it contains numerous Foraminifers, the shells of which are in some species so flattened that they resemble pieces of money. In many cases, moreover, the size increases the resemblance. The sea in which they lived was of great extent. The pyramids are built of Nummulitic Limestone, and the Nummulites are traditionally said to be the petrified remains of the lentils on which the children of Israel were fed by Pharaoh. They occur also in Asia Minor, Persia, on the Himalayas, and in Thibet, where they now rise to a height of 5000 metres.

Flysch

The Flysch is a very remarkable and important deposit. The name is a local Bernese expression, which was adopted by Studer.

Flysch is sometimes marly, sometimes calcareous, sometimes sandy. It is often slaty, and is extensively worked. It attains a thickness of nearly 2000 metres, and is evidently marine, but except in the slates of Matt, the only fossils found in it have been certain impressions which have been supposed to be Seaweeds, or perhaps Worm burrows. What are the conditions under which these have been preserved when all other organic remains have perished, is a mystery. The Flysch mountains present soft outlines, and their slopes present a rich carpet of vegetation.

These are the two principal deposits of the Eocene period, so far as Switzerland is concerned. In other strata numerous fossils have been found, including many Mammalia, and even a Monkey.

Miocene

During this period the main elevation of the Alps took place. We should naturally expect that rapid rivers would rush down from the heights bringing masses of gravel with them, and in fact we find enormous deposits of coarse gravel, often cemented into a hard rock, and containing blocks six inches, a foot, and even sometimes as much as a yard in diameter. This conglomerate is known as the Nagelflue, and the materials of which it is composed become gradually finer as we recede from the Alps, forming a more or less marly deposit known as the Mollasse. It attains a great thickness; indeed the whole of the Rigi from the Lake of Lucerne to the summit consists of Nagelflue. The Mollasse is composed of several deposits, some fresh-water and some marine; it is probable that the conditions may have been different in different parts of what are now the Swiss lowlands. The pleasant scenery of central Switzerland is greatly due to the Mollasse. The Freshwater Mollasse is generally soft, but the Marine beds afford excellent building materials. Large quantities are brought to Zürich from the upper part of the lake. It contains beds of brown coal and is rich in fossils. Indeed the deposits at Oeningen contain perhaps the richest collection of fossils in the world. Taking the Miocene period as a whole we know nearly 1000 species of plants and 1000 insects; of reptiles 32 species have been discovered, whereas in Switzerland now there are only 27. As regards Mammals 59 have been determined, while at present Switzerland contains 62; but though the numbers are so nearly the same, the species are all different and belong to very different groups. Of the present species 15 are bats, but no bat has been found in the Swiss Miocene. It contains on the other hand no less than 25 Pachyderms. The Wild Boar is the only present representative of the order, but during the Miocene period Tapirs and tapir-like Palæotheria, the horse-like Anchitherium, two species of Mastodon, the Dinotherium and no less than 5 species of Rhinoceros, roamed over the Swiss woods and plains. Of plants we know already 1000 species. Many resemble, and are probably ancestral forms of, those now flourishing in very distant parts of the world. Thus there are several Sequoias, one of which (Sequoia Langsdorfii) closely resembles the Redwood of California, and another (Sequoia Sternbergii) the gigantic Wellingtonia. Another species resembles the Marsh Cypress of the southern United States. There are also Australian types such as Hakeas and Grevilleas, while Palms, Liquidambars, Cinnamon, Figs, Camphor trees, and many other southern forms also occur. Of Oaks Prof. Heer has described no less than 35 species.

Moreover many of the Miocene plants have been found in the far North, implying a comparatively uniform and mild climate. Thus Sequoia Sternbergii is abundant in the lignites of Iceland, and Sequoia Nordenskioldi has been found in Greenland. As a whole the Flora resembles that of the present day, but represented by types now scattered over the whole world, and has most affinity with that of North America, as it contains over 200 North American against 140 European types. They have as a rule small and wind-fertilised flowers. Those which are more conspicuous, and which add so much beauty to our modern flora, were less numerous in Miocene times; and many families are altogether absent, such as Rosaceæ, Crucifers, Caryophyllaceæ, Labiatæ, Primulaceæ, etc. Bees and Butterflies, though already existing, had not yet so profoundly modified and developed the flowers. The Miocene species were all killed off or driven south by the Glacial Period and succeeded by others better able to stand a cold climate. There was on the contrary no such complete change in the marine flora and fauna.

SUMMARY

Looking at the Alps as a whole the principal axis follows a curved line from the Maritime Alps towards the north-east by Mont Blanc, Monte Rosa,[1] and St. Gotthard to the mountains overlooking the Engadine.

The geological strata follow the same direction. North of a line running through Cham-

[1] This name has no reference to color, but is derived from "reuse," a local name for glacier.

bery, Yverdun, Neuchâtel, Soleure, and Olten to Waldshut on the Rhine are Jurassic strata; between that line and a second nearly parallel and running through Annecy, Vevey, Lucerne, Wesen, Appenzell, and Bregenz on the Lake of Constance, are the lowlands, occupied by later Tertiary strata; between this second line and another passing through Albertville, St. Maurice, Leuk, Meiringen, and Altdorf lies a more or less broken band of older Tertiary strata, south of which are first a Cretaceous zone, then one of Jurassic age, followed by a band of crystalline rocks, while the central core, so to say, of the Alps, consists mainly of Gneiss or Granite. If we draw a line across Switzerland, say from Basle to Como, we find from Basle to Olten, say to the line of the Aar, Jurassic formations thrown into comparatively gentle undulations, and stretching from south-west to north-east. From Olten to Lucerne, the great plain of Switzerland is made up of upper Tertiary strata, known as Mollasse, and Nagelflue, consisting of sand and gravel washed down from the rising mountains and deposited partly in a shallow sea, partly in lakes. At Lucerne we come upon Eocene strata, also a marine formation, which have been raised to a height of as much as 2000 metres.

Continuing in the same direction, and soon after passing Vitznau, we come upon

Cretaceous rocks, which occupy most of the canton of Nid Dem Wald. In Ob Dem Wald we find ourselves on Jurassic. In other parts of Switzerland a considerable thickness of Triassic strata appears beneath the Jurassic, and rests on Verrucano, one of the Carboniferous series, but along our line the Jurassic region is immediately followed by Crystalline rocks, and Gneiss, forming the great Central ridge of Switzerland, and reaching as far as the Lake of Como. On the south of the mountain range, as on the north, the Gneiss is followed in succession by Carboniferous, Triassic, Jurassic, Cretaceous, and Tertiary strata, but they form narrower belts. Bellagio is on Trias; from the Island of Comacino the Gulf of Como is surrounded by Jurassic strata, south of which is a band of Cretaceous, running from the Lago Maggiore, opposite Pallanza, by Mendrisio, Como, Bergamo, and the south end of the Lago d'Iseo to Brescia, and so on further to the east.

Speaking roughly then we may say that the backbone of Switzerland consists of Gneiss and Granite, followed on both sides by Carboniferous, Triassic, Jurassic, Cretaceous, and Tertiary strata. These however are all thrown into a succession of gigantic folds, giving rise to the utmost complexity. The similarity of succession on the two sides of the ridge gives reason for the belief that the Carboniferous, Triassic, Jurassic, and Cretaceous strata north and south of the Alps were once continuous, and this impression is confirmed by other evidence, as will be shown in the following chapters.

CHAPTER II

THE ORIGIN OF MOUNTAINS

There rolls the deep where grew the tree.
　　O earth, what changes hast thou seen!
　　There, where the long street roars, hath been
The stillness of the central sea.

The hills are shadows, and they flow
　　From form to form, and nothing stands;
　　They melt like mist, the solid lands,
Like clouds they shape themselves and go.

TENNYSON.

THE true mountain ranges, that is to say, the elevated portions of the Earth's surface, are the continents themselves, on which most mountain chains are mere wrinkles; nevertheless when we speak of mountains, we mean as a rule those parts of the land which stand high relatively to the sea-level.

Mountain ranges in this sense may be classed under two main heads,[1] viz.:—

I. Table mountains.
II. Folded mountains.

[1] I say "main" heads, because in certain cases there may be other explanations. Von Richthofen has suggested that the Dolomites of the Tyrol were originally coral reefs.

The highest points or peaks may be again divided into two classes—volcanoes, and those due to weathering.

Volcanoes

Volcanoes have had comparatively little effect on the scenery of Switzerland. There is only one group of hills in Switzerland, those of Hohgau near the Lake of Constance, which is of Volcanic origin.

There are indeed certain isolated masses of igneous rock, as for instance in the Chablais, and again near Lauchern in Wandelibach, which are probably the necks of ancient Volcanoes.

Mountains of Denudation.

Let us imagine a country raised above the water with a gradual and uniform slope towards the sea. Rivers would soon establish themselves, guided by any inequalities of the surface, and running at more or less equal intervals down to the water level. They would form valleys, down the sides of which secondary rivulets would flow into the main streams. The rain and frost would denude with especial rapidity those parts of the surface which offered the least effective resistance, and thus not only would the original watershed be cut into detached summits, but secondary ridges would be formed approximately at right angles, to be again cut into detached summits like the first.

The general opinion of geologists used, however, to be, in the words of Sir R. Murchison, that " most of the numerous deep openings and depressions which exist in all lofty mountains were primarily due to cracks which took place during the various movements which each chain has undergone at various periods."

In support of this view such gorges as those of Pfäffers, the Trient, the Gorner, the Aar, etc., were quoted as conclusive cases, but even these are now proved to have been gradually cut down by running water.

The rapidity of denudation is of course affected greatly by the character of the strata, so that the present level depends partly on the original configuration, partly on the relative destructibility of the rock. The existing summits are not those which were originally raised the highest, but those which have suffered the least. And hence it is that so many of the peaks stand at about the same level. Every one who has ever stood at the top of such a mountain as the Piz Languard, which I name as being so easily accessible and so often visited, must have been struck by this fact; and must have noticed that the valleys are a far less important part of the whole district than they seem when we are below. The Matterhorn is obviously a remnant of an ancient ridge, which gives the peculiar straight line at the summit. The noble mass of the Bietschorn again, which forms such an imposing object as we look down the valley of St. Niklaus across the Rhone at Visp, is a part of the surrounding granite which has resisted attack more successfully than the rest of the rock. The mountain crests, solid as they look from a distance, are often formed of detached fragments, shattered by storms, and especially by frost.

Mountain Ranges

The present temperature of the Earth's surface is due to the Sun, that supplied from the original heat of the planet being practically imperceptible. The variations of temperature due to seasons, etc., do not extend to a greater depth than about 10 metres. Beyond that we find as we descend into the Earth that the heat increases on an average about 1° Fahr. for every 50 metres.[1] Even, therefore, at comparatively moderate depths the heat must be very great. Many geologists in consequence, have been, and are, of opinion that the main mass of the Earth consists of molten matter. We know, however, that the temperature at which fusion takes place is raised

[1] Agassiz, however, in the case of the Calumet Mine near Lake Superior, found a rate of 1° Fahr. for every 223 ft. (*Amer. Journ. of Science*, 1895).

by pressure, and it must not, of course, be assumed that the temperature continues to increase so rapidly beyond a certain depth. Other great authorities,[1] therefore, are of opinion that the mass of the Earth, though intensely hot, is solid, with, no doubt, lakes of molten matter. In either case the central mass continues slowly to cool and consequently to contract. The crust, however, remains at the same temperature and consequently of the same dimensions. This being so, under the overwhelming force of gravity one of the two things must happen. Either (1), parts of the crust must break off and sink below the rest; or (2), the surface must throw itself into folds.

Table Mountains

Where the first alternative has happened we find more or less numerous faults.

Those parts which have not sunk, or which have sunk less than the rest, remain as tabular mountain masses, more or less carved into secondary hills and valleys by the action of rain and rivers. Such, for instance, is the Table Mountain of the Cape of Good Hope; its relative height is not due to upheaval, but to the surrounding districts having sunk.

As the crust of the Earth cooled and solidified, certain portions "set," so to say,

[1] See, for instance, Lord Kelvin, *Lectures and Addresses*, vol. ii.

sooner than others; these form buttresses, as it were, against which the surrounding areas have been pressed by later movements. Such areas have been named by Suess "Horsts," a term which it may be useful to adopt, as we have no English equivalent. In some cases where compressed rocks have encountered the resistance of such a "Horst," as in the north-west of Scotland and in Switzerland, they have been thrown into most extraordinary folds, and even thrust over one another for several miles.

Murchison long ago expressed his surprise at the existence of great plains such as those of Russia and Siberia. L. v. Buch suggested as a possible explanation that they rested on solid masses which had cooled down early in the history of the planet, and thus had offered a successful resistance to the folds and fractures of later ages.

Folded Mountains.

The Swiss mountains, however, belong to another class, and have a very different character. They are greatly folded and compressed (see Figs. 23-26). Fig. 1 represents the Cascade of Arpenaz in the valley of the Arve. It shows a grand arch, but does not include the whole fold, which takes the form of an S, the middle part only being included in the photograph.

FIG. 1.—Cascade of Arpenaz.

It used to be supposed that mountains were upheaved by forces acting more or less vertically from below upwards, and the plutonic rocks which occupy the centre of mountain ranges were confidently appealed to in support of this view. It must be confessed that when we first visit a mountainous region, this theory seems rational and indeed almost self-evident. It is now, however, generally admitted that such an explanation is untenable; that the plutonic rocks were passive and not active; that, so far from having been the moving force which elevated the mountains, they have themselves been elevated, and that this took place long after their formation. Near the summit of the Windgälle, in the Reuss district, is, for instance (Fig. 24), a mass of Porphyry. The eruption of this Porphyry must have taken place before the Jurassic period, for rolled pebbles of it occur in that rock. On the other hand, the fold on the summit of the Windgälle contains Eocene strata. The origin of the Porphyry then is earlier than the Jurassic; the elevation of the mountain is later than the Eocene. It is clear, therefore, that the Porphyry had nothing whatever to do with the origin of the Windgälle mountain.

The plutonic rocks have moreover produced no effect on the strata which now rest on them. If, however, they had been intruded in a molten condition, they must have modified the rocks for some distance around. It is evident therefore that the igneous rocks had cooled down before the overlying strata were deposited. The elevation of the Alps only commenced in the Tertiary period, but we know that the Granite of the southern Alps is, for the most part, pre-Carboniferous, that the Porphyry of Botzen belongs to the Permian period, the younger Porphyry to the Trias, and that the Gneiss of the central range of the eastern Alps is still older; it is evident then, that these plutonic rocks can have taken no active part in the upheaval of the Alps, which occurred so much later.

We may, indeed, lay it down as a general proposition that folded mountains are not due to volcanic action. When the two are associated, as in the Andes, the volcanoes are due to the folding and crushing, not the folding to the volcanoes.

The Alps then have not been forced up from below, but thrown into folds by lateral pressure. This view was first suggested by De Saussure, worked out in fuller detail by Sir Henry De La Bèche in 1846, and recently developed by Ball, Suess, and especially by Heim.[1]

[1] See especially Heim's great work, *Untersuchungen ü. d. Mechanismus d. Gebirgsbildung*. I ought perhaps, however, to add that this view is not universally accepted.

Moreover, as the following sections show, (Figs. 5, 23-26) we have every gradation from the simple undulations of the Jura (Fig. 5) to the complicated folds of the Alps (Figs. 1, 23-26).

But why are the surface strata thus thrown into folds? When an apple dries and shrivels in winter, the surface becomes covered with ridges. Or again, if we place some sheets of paper between two weights on a table, and then bring the weights nearer together, the paper will be crumpled up.

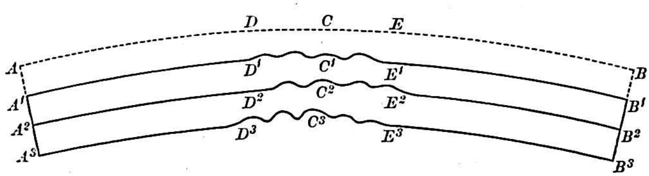


FIG. 2.—Diagram in explanation of folded mountains.

In the same way let us take a section of the Earth's surface $A\ B$ (Fig. 2) and suppose that, by the gradual cooling and consequent contraction of the mass, $A\ B$ sinks to $A^1\ B^1$, then to $A^2\ B^2$, and finally to $A^3\ B^3$. Of course if the cooling of the surface and of the deeper portion were the same, then the strata between A and B would themselves contract, and might consequently still form a regular curve between A^3 and B^3. As a matter of fact, however, the strata at the surface of our globe have long since approached a constant temperature. Under these circumstances there would be no contraction of the strata between A and B corresponding to that in the interior, and consequently they could not lie flat between A^3 and B^3, but must be thrown into folds, commencing along any line of least resistance. Sometimes, indeed, the strata are completely in-

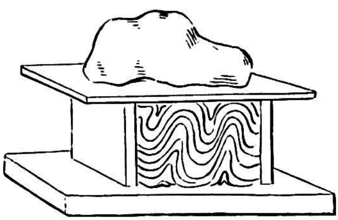


FIG. 3.—Hall's Experiment illustrating Contortion.

verted, and in other cases they have been squeezed for miles out of their original position. "The great mountain ranges," says Geikie, "may be looked upon as the crests of the great waves into which the crust of the Earth has been thrown." Sir James Hall illustrated the origin of folds very

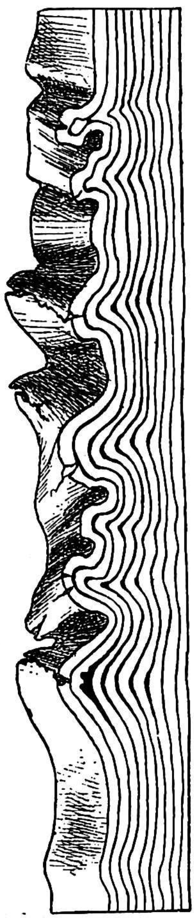


FIG. 4.—Showing the artificial folds produced in a series of layers of clay on indiarubber, according to an experiment by Prof. A. Favre.

simply (Fig. 3) by placing layers of cloth under a weight, and then compressing the two sides, and more complete experiments have since been made by Favre, Ruskin and Cadell.

Fig. 4 shows the result of one of Favre's experiments, in which he used the contraction of an indiarubber band to produce the folds.

The shortening of the Jura amounts to about one-fifteenth. The strata between Basle and the St. Gotthard, a distance of 130 miles, would, if horizontal, occupy 200 miles. Heim estimates the total compression of the Alps at a minimum of 120,000 metres.[1] The original breadth of the strata forming the Aarmassif was at least double the present, and the same may be said of the central range. The Appalachians are calculated to be compressed from 150 miles to 65.

It very seldom happens that such a range of mountains consists of a single fold. There are generally several, one being as a rule formed first, and others outwards in succession. In both the Alps and the Jura, the southern folds are the oldest. In Central America, again, there are several longitudinal ranges, and the volcanoes are generally situated on cross lines of fracture, so that they are in rows, at right angles to the general direction of the moun-

[1] *Mechanismus d. Gebirgsbildung*, v. 2.

tains, and in almost every case the outer crater, or that towards the Pacific, is the only one now active.

A glance at any good map of the Jura will show a succession of ridges running parallel to one another in a slightly curved line from south-west to north-east. That these ridges are due to folds of the Earth's surface is clear from the following figure (Fig. 5) in Jaccard's work on the Geology of the Jura, showing a section from Brenets due South to Neuchâtel by Le Locle. These folds are comparatively slight and the hills of no great height. In the Alps the strata are much more violently dislocated and folded.

The mountains seem so high that we are apt to exaggerate the relative elevation. The following figure (Fig. 6) by Rütimeyer gives the outline of the Alps from Basle to near Milan. This section is only intended to indicate the relative height, and is supposed to follow the line of one of the great valleys. Even so, however, it ought to have shown the sudden dip to the south of the main ridge.

The folded structure throws light on the curious fact that there are much fewer faults in Switzerland than in such a region as, for instance, that of our coal fields.

In folded districts the contortions are often so great that if we could not follow every step they would certainly be regarded as incredible.

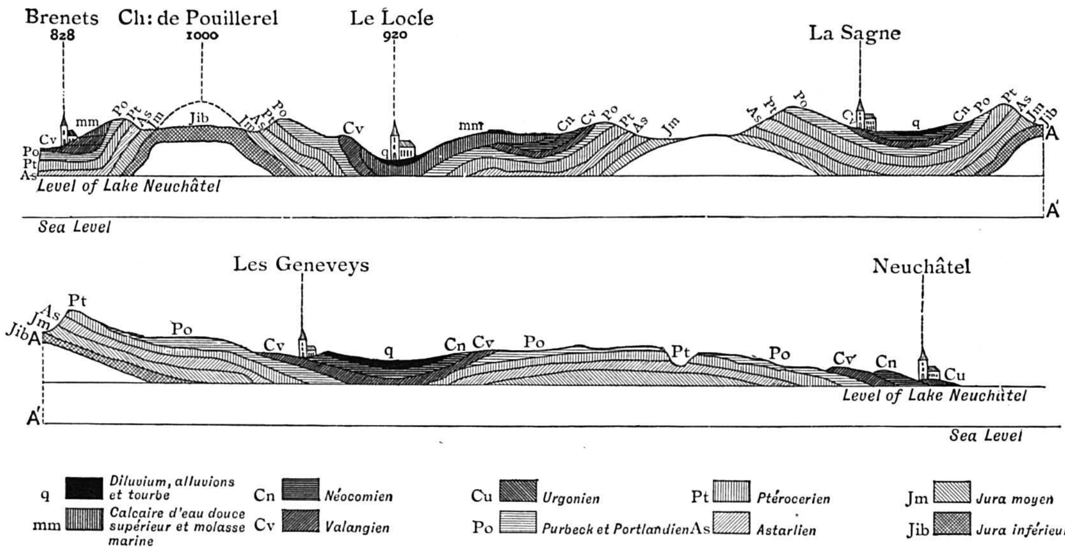


Fig. 5.—Section across the Jura from Brenets to Neuchâtel.

Previous folds are themselves in some cases refolded, and in others the lateral pressure has not only raised the strata into a vertical position, as for instance the Chalk and Tertiary sands of Alum Bay in the Isle of Wight, but has in some cases pushed the folds for miles, and has even thrown them over, so that the sequence is inverted, and the more ancient lie over the more recent strata in reverse order. As the cooling, and consequent contraction of the Earth, is a continuous process, it follows that mountain ranges are of very different ages; and, as the summits are continually crumbling down, and rain and rivers carry away the debris, the mountain ranges are continually losing height. Our Welsh hills, though comparatively so small, are venerable from their immense antiquity, being far older, for instance, than the Vosges, which themselves, however, were in existence while the strata now forming the Alps were still being deposited at the bottom of the Ocean. But though the Alps are from this point of view so recent, it is probable that the amount which has been

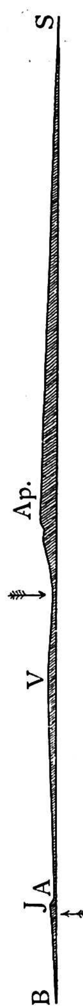


FIG. 6.—Section from Basle across the Alps to Senago, north-west of Milan. *B*, Basle. *J*, Jura. *A*, Aar, near Olten. *Ap*, Alps. *S*, Senago. Inclination from Basle to summit of Jura, 1° 37′; from Basle to the summit of the Alps, 1° 43′.

removed is almost as great as that which still remains. They will, however, if no fresh

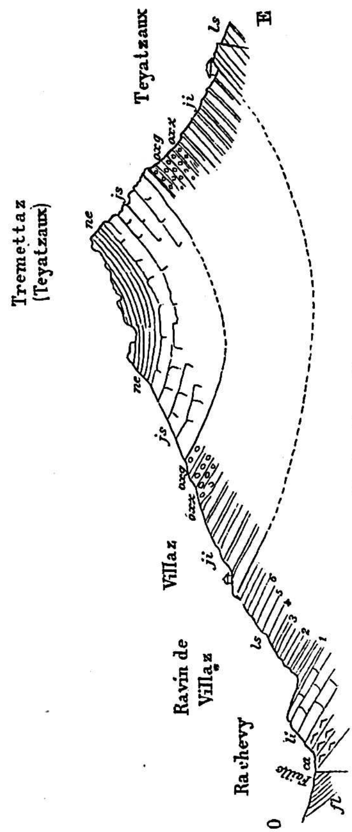


FIG. 7.—Tremettaz.

elevation takes place, be still further reduced, until nothing but the mere stumps remain.

What an enormous amount of denudation has already taken place is shown for instance in Fig. 7, representing the mountain of Tremettaz near the valley of the Rhone, between the Niremont and the valley of the Sarine, where it is evident, not only that the strata have been cut off, but that what is now the top of the mountain was once the bottom of a valley.

The edges of strata which appear at the surface of the ground are termed their "Outcrop." Sometimes they are horizontal, but if not, the inclination is termed their "Dip" (Fig. 8, *B*). A horizontal line drawn at a right angle to the Dip is called the "Strike" (Fig. 8, *A*) of the rocks. If the surface of the ground is level this will coincide with the outcrop. In a mountainous district such as Switzerland this is however rarely the case.

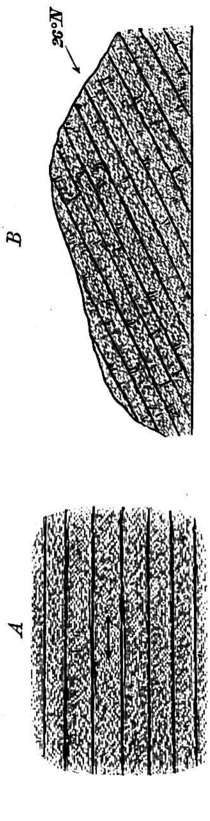


Fig. 8.—Diagram showing (A) the "Strike" and (B) the "Dip" of strata.

Where strata have been bent, as in Fig. 9, it is called a monoclinal fold. Where the subterranean forces have ruptured the strata and pushed the one side of the crack more

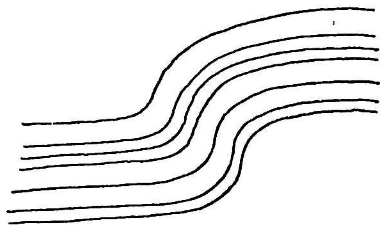


FIG. 9.—Monoclinal Fold.

or less upwards or downwards (Fig. 10), it is termed a fault.

Faults may be small, and the difference of height between the two sides only a few

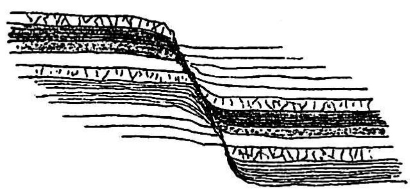


FIG. 10.—A Fault.

inches. On the other hand, some are immense. In the case of one great fault described by Ramsay, the difference is no less than 29,000 feet, and yet so complete has been the denudation that the surface shows no evidence of it, and one may stand with a foot on each side, unconscious of the fact that the stratum under the one represents a geological horizon so much above that under the other.

When the strata bent somewhat before the fracture we have a fold-fault (Fig. 11).

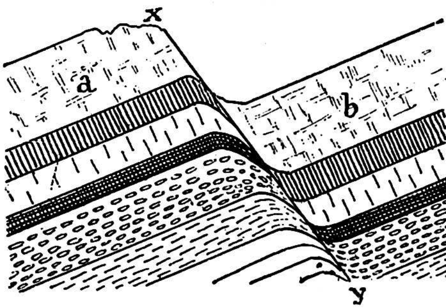


FIG. 11.—Line of Fault at the upper displaced bed. The beds are bent near the fault by the strain in slipping.

Where a fold is much compressed the limbs would become thinner and thinner (Fig. 12), while the strata in the arch and the trough would be compressed and consequently widened.

FIG. 12.—An Inclined Fold.

When the arch *A*, instead of being upright is thrust to one side, it is said to be inclined or recumbent (Fig. 12).

Where strata are thrown into folds the

convex portion is termed an anticlinal (Fig. 14, *A*) and the concave a synclinal (Fig. 14, *B*). The same terms are applicable when the surface has been planed down so that the strata would dip as in Fig. 13.

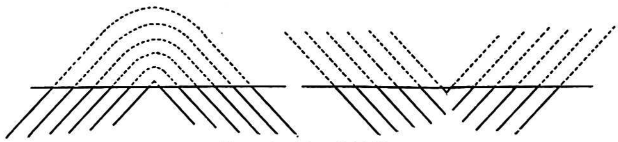


FIG. 13.—Razed Folds.

The inner strata of any fold are called the core, those of an anticlinal (Fig. 14, *A*) being called the arch core, those of a synclinal (Fig. 14, *B*) the trough core.

It is obvious of course that when strata are thrown into such folds, they will, if strained too much, give way at the summit. Before doing so, however, they are stretched and consequently loosened, while on the other hand the strata at the bottom of the fold are

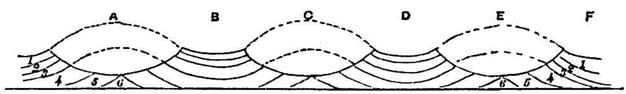


FIG. 14.—Diagram showing Anticlinal and Synclinal Folds.

compressed; the former, therefore, are rendered more susceptible of disintegration, the latter on the contrary acquire greater powers of resistance.

The above diagram, Fig. 14, represents six strata (1-6) supposed to be originally of approximately equal hardness, but which, after being thrown into undulations, are rendered more compact in the hollows and less so in the ridges. Denudation will then act more effectively at *A*, *C*, *E*, than at *B*, *D*, *F*, and when it has acted long enough the surface will be shown by the stronger line. This will be still more rapidly the case if some of the strata are softer than others. Where they are brought up to the surface erosion will of course act with special effect. Hence it often happens that hills have become valleys, and what were at first the valleys have become mountain tops. As an illustration of the former I may mention the Geschenenthal, and (Fig. 24) Maderanerthal, and the valley of the Tinière (Fig. 98); of the latter, the Tremettaz (Fig. 7) or the Glärnisch.

In other cases where the summit is not at the very base of the trough, the edges of some stratum rather harder than the rest, project as two more or less pointed peaks, leaving a saddle-shaped depression in the centre.

Highly inclined strata are often worn away so as to form a kind of wall, sometimes so thin that it is actually pierced by a natural hole, as for instance the Martinsloch above Elm, in Glarus. There is another of these orifices near the summit of the Pilatus, one in the Marchzahn, a mountain of the Gastlose chain, and another in the Piz Aela, also known for that reason as Piz Forate, between the Albula and the Oberhalbstein Rhine.[1]

When we look at these abrupt folds and complicated contortions, the first impression is that they must have been produced before the rocks had solidified. This, however, is not so. They could not indeed have been formed except under pressure. We must remember that these rocks, though they are now at or near the surface, must have been formerly at a great depth, and where the pressure would be tremendous. Even in tunnels, which of course are comparatively near the surface, it is sometimes found necessary to strengthen and support the walls which would otherwise be crushed in. The roadways in coal-mines are often forced up, especially where two passages meet. This indeed is so common that it is known as the "creeps." In deep tunnels it has not unfrequently happened that when strata have been uncovered they have suddenly bent and cracked, which shows that they were under great lateral pressure. Yet the deepest mine only reaches 800 metres.

Treska[2] has shown by direct experiment that the most solid bodies, lead, tin, silver, copper, and even steel, will give way and "flow" under a pressure of 50,000 kilograms

[1] Theobald's Graubünden, *Beitr. z. Geol. Karte d. Schw.*, ii.
[2] *Comptes Rendus*, 1874.

per square centimetre. Moreover, there is direct and conclusive evidence that the Swiss rocks were folded after solidification. In many cases contorted rocks contain veins (Fig. 16) which are in fact cracks filled up with chalcite, etc. Such fine fissures, however, can only occur in hard rock. Again the Eocene contains rolled pebbles of Gneiss, Lias, Jurassic, etc., which must therefore have become hard and firm before the Eocene period,[1] while the folding did not occur till afterwards. It is clear therefore that when the folding took place the rocks were already solidified. No doubt, however, the folding was a very slow process. It took place, and could only take place, deep down, far below the surface, under enormous pressure, and where the material was probably rendered somewhat more plastic by heat. In the later and higher rocks we find compression with fracture, in the earlier and lower rocks compression with folding. Whenever we find a fold we may be sure that, when formed, it was deep down, far below the surface.

In fact folds and fractures are the two means by which the interior strains adjust themselves. They replace one another, and in the marvellously folded districts of the Alps faults are comparatively few, though it must not be supposed that they do not occur. The

[1] Heim, *Mech. d. Gebirgsb.*, vol. ii.

nature of the rock has little influence on the great primary folds, but the character of the minor secondary folds depends much upon it. Many of the following figures give an idea of the remarkable folds and crumpling which the strata have undergone, so much so that they have been compared to a handful of ribbons thrown on to the ground.

It is obvious that before strata could be thrown into contortions such as these, they must have been subjected to tremendous pressure. They have consequently been much altered, and the fossils have been compressed, contorted, crushed, ground, and partly, or in many cases entirely, obliterated.

In parts of the great Glarus fold (see p. 290) the Hochgebirgskalk is reduced from a thickness of 450 to a few metres.[1] In other cases certain formations have been completely squeezed out. We must not therefore infer, from the absence of a given stratum in such cases, that it never existed.

Fig. 15 represents a piece of contorted mica schist, and it will be seen that the folds are a miniature of those to which on a great scale our mountains are due.

In many cases the rock is broken up into flat or more or less lenticular pieces, which have been squeezed over one another so that their surfaces have been rendered smooth

[1] Heim, *Mech. d. Gebirgsb.*, vol. ii.

and glistening. Such surfaces are known as slickensides. This process has sometimes been so intense and so general that hardly a piece

FIG. 15.—Hand Specimen of Contorted Mica Schist.

can be found which does not present such a polished surface. The particles of stone which now touch were once far apart, others which are now at a distance once lay close together.

The cracks, movements, and friction which result in such a structure must from time to time produce sounds, and the mysterious subterranean noises sometimes heard are perhaps thus produced.

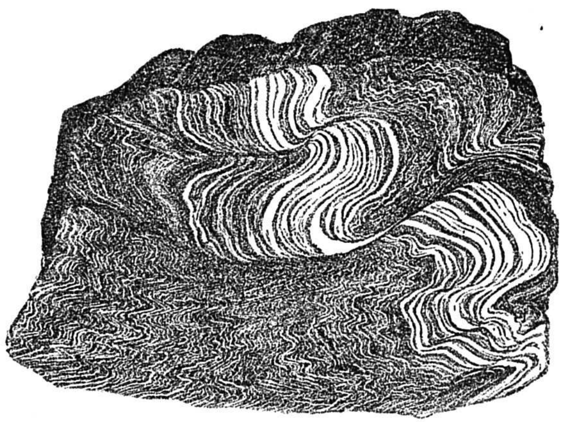


FIG. 16.—Section of Rothidolomite.

Fig. 16 represents a section of Rothidolomite, and it will be observed that, as we

FIG. 17.—Piece of Stretched Verrucano.

should expect theoretically, the strata are thinnest in the limbs, where they are squeezed out. This is visible in great mountain folds, as well as in hand specimens.

In the part of the curve where the effect of the force is to draw out the strata, they will as shown above, if capable of giving way, become thinner. If however they are not plastic they must crack, the combined width of the cracks affording the additional space. Fig. 17 represents a fragment of Verrucano thus drawn out.

In many cases fossils are compressed or torn, but still distinguishable. Fig. 18 represents Belemnites thus compressed and torn; but in all these cases the extension or tearing is due, not to a general extension of the rock, but to lateral thrust.

Fig. 19 represents a piece of nummulitic lime-

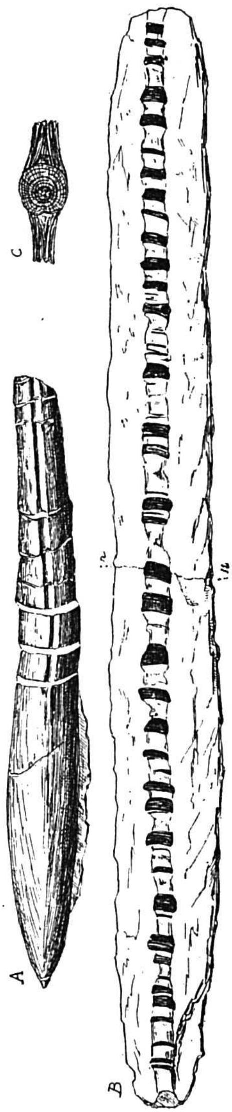


Fig. 18.—Stretched and broken Belemnites, $\frac{1}{2}$ size. *A*, Belemnites hastilis, slightly broken, Frête de Saille. *B*, Specimen much drawn out. *C*, Section at *n*.

stone when the rock has not only been fractured along the lines *a b*, but two sides of the vein *a* have been evidently displaced. At a later date another fracture has taken place along the line *c d*.

Some rocks have been so kneaded and ground together that in many places it is rare to find a cubic millimetre next its original neighbours.[1] In many places fragments and

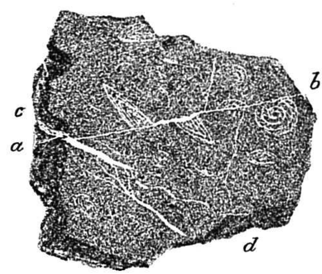


FIG. 19.—Fragment of Nummulitic Limestone.

wedges of one formation have been forced into another.

In the Tertiary slates of the Sernfthal at Plattenberg near Matt are well-preserved remains of fish belonging to the genus Lepidotus. Agassiz thought he could distinguish, and described, six species, but Wettstein has shown that they all belong to one and the same, and that the differences of form are merely due to the position in which the

[1] Heim, *Mech. d. Gebirgsb.*, vol. i.

specimens happened to lie with reference to the direction of pressure.

In many cases the pressure has produced "cleavage," and turned the rocks into shale or slate, so that they split into more or less perfect plates or films. The direction of cleavage is quite independent of the stratification, which it may cross at any angle. Heim distinguishes three forms of cleavage. Firstly, that due to the formation of slickensides as just described (*ante*, p. 49). The second kind of cleavage is due to the minute particles in the rock being flattened by, and arranged at right angles to, the pressure, as shown in Figs. 20 and 21.[1]

The third is produced by all the laminæ or elongated particles being arranged by the pressure in lines of least resistance, so that they are forced to lie parallel to one another.

It is, however, by no means always easy, especially in the crystalline rocks, to distinguish cleavage from stratification. The structure of the crystalline rocks, which form the base of the Windgälle, and which Heim regards as partly stratification, is considered by some geologists to be all cleavage.

The fact that cleavage has been produced by pressure was first demonstrated by Sharpe, and afterwards with additional evidence by Sorby and Tyndall. In fact, under great pres-

[1] Geikie, *Text-book of Geology*.

sure solid rock behaves very much like ice in a glacier.

FIG. 20.—Section of a fragment of argillaceous rock.

Cleavage and folding are both due to the same cause. They have arisen simultaneously,

FIG. 21.—Section of a similar rock which has been compressed, and in which cleavage structure has been developed.

and are different manifestations of the same mechanical action.

CHAPTER III

THE MOUNTAINS OF SWITZERLAND

Erst dann haben wir ein Gebirg erkannt, wenn sein Inneres durchsichtig wie Glas vor unsern geistigen Auge erscheint.—THEOBALD.

We do not really know a mountain until its interior is to our mental eye as clear as crystal.

THE Swiss mountains, as indicated in the preceding chapter, are now considered to be due, not to upheaval from below, but to lateral pressure.

This acted from the south-east to north-west, and took place at a comparatively recent period, mainly indeed after the end of the Eocene period. There are good grounds for supposing that a former range occupied the site of the present Alps at an early period, and the Carboniferous strata show considerable folds (Fig. 22), over which the Permian and more recent strata were deposited.

The Carboniferous Puddingstone of Valorsine, which contains well-rounded pebbles and boulders, shows that there must have been mountains and rapid rivers at this period. These ancient mountains, however, were removed by denudation, and the whole country sunk below the Sea. Between the Eocene and the Miocene was a second period of disturbance, and all the strata, including the Eocene, were folded conformably together.[1] The main elevation of the Alps was, however,

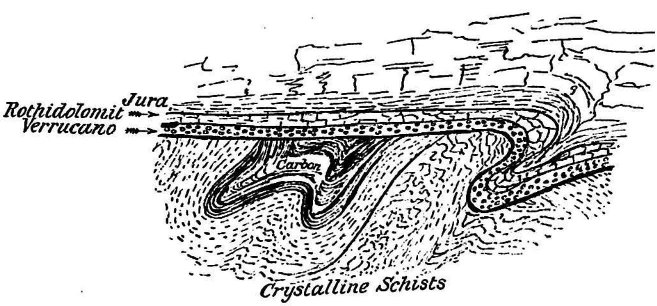


FIG. 22.—Carboniferous Folds on the Biferten Grat.

between the Miocene and the Glacial periods. Miocene strata attain in the Rigi a height of 6000 feet. By this much at least then the Alps must have been raised since the close of this comparatively recent period.

"It is strange to reflect," says Geikie, "that the enduring materials out of which so many of the mountains, cliffs, and pinnacles of the Alps have been formed are of no higher geological antiquity than the London Clay and

[1] Heim, *Mech. d. Gebirgsb.*, vol. i.

other soft Eocene deposits of the South of England."[1]

Unfortunately we seldom see a map, except on quite a small scale, of the whole Alps. We have separate maps of France, of Switzerland, of Italy, and of the Austrian dominions. But to get a good general idea of the whole Alps, we require not only Switzerland, but parts of France, Italy, and Austria. If we have such a map before us we see that, with many minor irregularities, the Alps are formed on a definite plan. The principal axis follows a curved line encircling the North of Italy; commencing with a direction almost due north in the Maritime Alps, sweeping round gradually to the east.

The direction appears to have been determined by the pre-existing Central Plateau of France and the Black Forest, which probably formed a continuous barrier before the subsidence of the Rhine valley. They are in fact ancient pillars, far older than the Alps, and Switzerland has been thrown into waves or folds by compression against these great buttresses.

"To account for the conformation of the Alps," says Tyndall, "and of mountain regions generally, constitutes one of the most interesting problems of the present day. Two hypotheses have been advanced, which may be

[1] Geikie's *Text-book of Geology*.

respectively named the hypothesis of *fracture* and the hypothesis of *erosion*. Those who adopt the former maintain that the forces by which the Alps were elevated produced fissures in the earth's crust, and that the valleys of the Alps are the tracks of these fissures. Those who hold the latter hypothesis maintain that the valleys have been cut out by the action of ice and water, the mountains themselves being the residual forms of this grand sculpture. To the erosive action here indicated must be added that due to the atmosphere (the severance and detachment of rocks by rain and force), as affecting the forms of the more exposed and elevated peaks."[1]

This was written thirty years ago and has been confirmed by the subsequent researches of geologists. While the folding referred to in the last chapter has determined the position of many of the Swiss valleys, "fracture" has played but a subordinate part, and to denudation and erosion, as Tyndall himself always maintained, the present conformation of the country is mainly due.

Switzerland is divided roughly into equal parts by four great rivers,—the Rhine, the Rhone, the Reuss, and the Ticino. These four rivers rise on the same great "central

[1] Tyndall, "Conformation of the Alps," *Philosophical Mag.*, Oct. 1864. See also Scrope, "On the Origin of Valleys," *Geol. Mag.* 1866.

massif." The valleys are not, however, of the same character. The Rhine-Rhone valley from Martigny to Chur is a "geotectonic" valley; its direction coincides with the direction or "strike" of the strata, and it was originally formed by a great fold in the strata.

The Reuss and Ticino valleys (except the upper part of the Reuss in the Urserenthal, which is in fact a part of the Rhone-Rhine valley and the upper part of the Ticino in the Val Bedretto, which is also a longitudinal valley) are transverse; they cross the strata approximately at right angles, and consequently the rocks on the two sides are the same. They are entirely due to erosion.

In the Jura, where the foldings are comparatively gentle and the denudation has been much less, the present configuration of the surface follows more closely the elevations and depressions due to geological changes (see Fig. 5).

In the Alps the case is different, and the denudation has so far advanced that we can at first sight trace but little relation between the valleys, as indicated by the river courses and the mountain chains, and the geological structure of the country. There are many cases of anticlinal valleys; that is to say, of valleys (see *ante*, p. 45) which run along what was at one time the summit of an arch, as, for instance, the Maderanerthal (Fig. 24) and the Val de la Tinière (Fig. 98).

In other cases a piece is cut off from the rest of the massif to which it belongs, as, for instance, the Frusthorn from the Albula massif by the Valserthal.

There are others where a mountain, or range of mountains, occupies the line of a former valley. This is the case for instance with the mountain ridge which runs between the Rhine and the upper Linth from the Kistenpass at the head of the Limmerbach to the south of the Limmern Glacier, by the Bifertenstock to Piz Urlaun and Stock Pintga or the Stockgron.[1] This range of mountains occupies the site of an original valley, but no doubt from the greater hardness of the rock and its position it has offered a more successful resistance to attack; while the original mountains have been washed away.

In this way some at any rate of the transverse ranges have, as it were, been carved out. Thus the Safienthal—the valley of the Glenner which falls into the Rhine at Ilanz—is bounded by ranges approximately at right angles to the main direction of the mountains. That on the left of the valley culminates in the Piz Ricin, Crap Grisch, Weissensteinhorn, and

[1] Heim, *Beitr. z. Geol. K. d. Schw.*, L. xxv.

Bärenhorn. In favourable light it can easily be seen from the opposite side of the valley, that the streams have cut out the valleys and are thus the cause of the mountains. This is a particularly clear illustration, because the strata are uniform along the whole line, so that the structure is not complicated by the presence of rocks of different character and hardness.

Indeed if we compare together two maps, in one of which the principal chains of mountains, and in the other the main river valleys, are brought out most prominently, they look at first sight so different that we should hardly suppose them to represent the same district.[1] It is evident therefore that the main agent which has determined many of the river valleys is not that which has given rise to the mountains. The courses of the rivers, though there have, as we shall see, been many minor changes, and exceptions due to other causes, still were determined by the folds into which the surface was thrown; while the present mountain summits are mainly the result of erosion and denudation.

We will now consider the evidence which leads to the conclusion that the fossiliferous strata formerly extended over the Central chain of the Alps. It is a common error to suppose that the limits of geological strata are those

[1] Heim, *Mech. d. Gebirgsb.*, vol. i.

which are now shown on the map. It requires little reflection however to show that this was not so. In the abyssal depths of the ocean deposit is portentously slow, and a long period would be represented by only a few inches of rock. Moreover, though a marine formation proves the existence of sea, the absence of a marine formation does not prove the existence of land. Strata may and often have been entirely removed. Our Cretaceous deposits, for instance, once extended far beyond their present limits. The same was the case with the Secondary deposits of Switzerland from the Trias to the Eocene. They extended completely over the Central mountains. If these mountains had been then in existence and the Secondary strata had been deposited round them, we should find evidence of shore deposits, with remains of animals and seaweeds such as live in shallow waters and near land. This is however not the case; we find no pebble beds such as would be the case near a shore, no gravels with pebbles of granite, gneiss, or crystalline schists, but deep-sea deposits of fine sediment evidently formed far from land. The southern shores of the Jurassic Sea were perhaps far away in Africa.[1] In the Triassic period there seems to have been a barrier between the Eastern and Western Alps, but subse-

[1] Heim, *Mech. d. Gebirgsb.*, vol. ii.; Baltzer, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.

quently the conditions must have been very similar.

Even the Eocene deposits show no evidence of a shore where the Alps now rise above them.

We have other proofs that the central chains were formerly covered by other strata. For instance, the Puddingstone of Valorsine at the head of the Chamouni valley, which belongs to the Carboniferous period, contains no granite or porphyry pebbles. The granite and porphyry strata of the district must therefore at that period have been protected by a covering of other rocks which have been since stripped off.

It is also significant that the pebbles of the Miocene Nagelflue which come from the neighbourhood are mainly of Eocene age. Neither the Crystalline rocks nor the older Secondary strata seem to have been then as yet uncovered.[1] There are indeed crystalline and Triassic pebbles in the Nagelflue, for instance, of the Rigi, but they do not belong to rocks found in the valley of the Reuss or on the St. Gotthard. They resemble those of Lugano, Bormio, the Julier, and other districts far away to the south-east.

We are not however dependent on these arguments alone, conclusive as they are. Remains of Secondary strata occur here and there in the Central district, and these are

[1] Heim, *Mech. d. Gebirgsb.*, vol. ii.

not fragments torn away from one another, but parts of a formerly continuous sheet, which have been preserved in consequence of being protected in the hollows of deep folds. That the Secondary strata were once continuous over the Central chain is well shown in the following figure (Fig. 23) drawn from the Rhone to the Averserthal and cutting the Binnenthal, Val Antigorio, Val Bavena, Val Maggia, Val Ticino, Val Blegno, Val Misocco and Val St. Giacome. It will be seen that all these valleys are primarily due to great folds, and that in each case we find at the bottom of the valleys remains of the Secondary strata nipped in between the Crystalline rocks.

Fig. 23.—Profile through the Gneiss masses between the Rhone at Viesch and the Averserthal. *I*, Aarmassiv; *II*, Gotthardmassiv; *III*, Monte Leone Masse; *IV*, Lebedun Masse; *V*, Antigorio Masse; *VI*, Tessiner Masse; *VII*, Monte di Sobrio Masse; *VIII*, Adula Masse; *IX*, Liro Masse; *X*, Suretta Masse. 1, Rhonethal; 2, Binnenthal; 3, Val Antigorio; 4, Val Bavona; 5, Val Maggia; 6, Tessinthal; 7, Val Blegno; 8, Val Misocco; 9, Val St. Giacomo; 10, Averserthal.

Fig. 24 shows a section after Heim, from the Weisstock across the Windgälle to the Maderanerthal. It is obvious that the valleys are due mainly to erosion, that the Maderaner valley has been cut out of the Crystalline rocks, *s*, and was once covered by the Jurassic strata *j*, which must have formerly

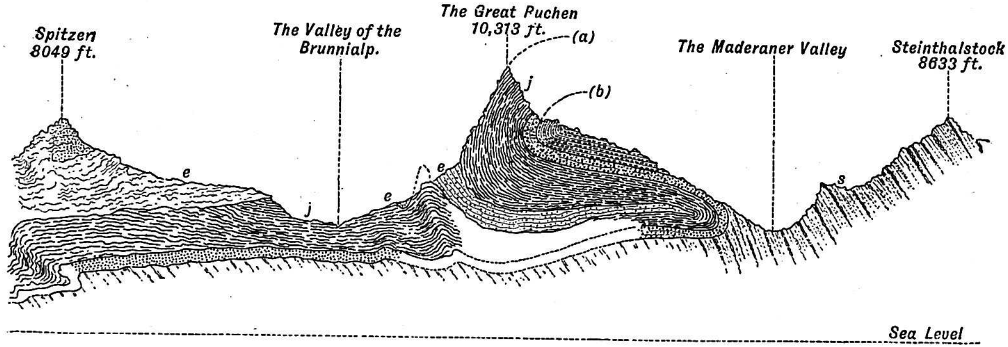


FIG. 24.—Section from the Weisstock across the Windgälle to the Maderanerthal.

passed in a great arch over what is now the valley.

Again it is clear (Fig. 25) that a great thickness of Crystalline rock has been removed from the summit of Mont Blanc. No doubt (see *ante*, p. 3) many thousand feet had been removed before the deposition of the Secondary strata. But even since its elevation the amount of erosion of the Granite itself has been considerable. How much we do not know, but 500 metres would probably be a moderate estimate. To this must be added the Crystalline Schists, say 1000 metres, and the Sedimentary rocks, which from what we know of their thickness elsewhere cannot be taken at less than 3000 metres. This therefore gives 4500 metres, or say 14,000 feet, which erosion and denudation have stripped from the summits of the mountains! Fig. 26 gives a section across the Alps, and it will be seen that the section across the St. Gotthard substantially resembles that of Mont Blanc.

Surprising, and even almost incredible, as this may at first sight appear, it becomes less difficult to believe when we remember that not only the great Miocene gravel beds which form the Central plain of Switzerland, but much of the deposits which occupy the valleys of the Rhine, Po, Rhone, Reuss, Inn, and Danube—the alluvium which form

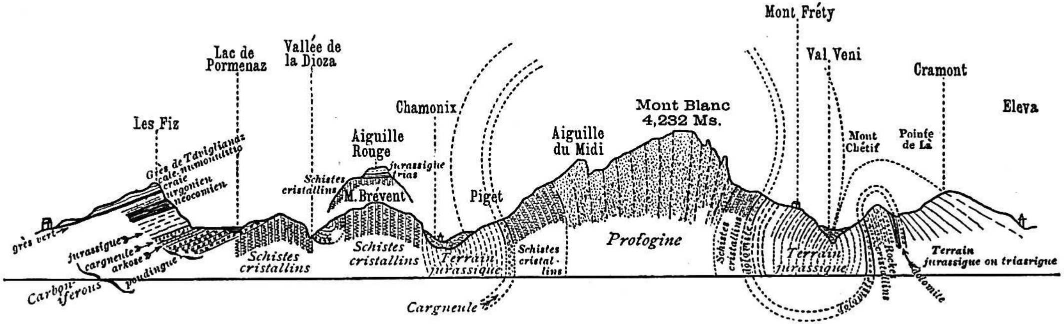


FIG. 25.—Section across the Mont Blanc range.

the plains of Lombardy, of Germany, of Belgium, Holland, and of South-east France are materials washed down from the Swiss mountains.

It is calculated that at the present rate of erosion the Mississippi removes one foot of material from its drainage area in 6000 years, the Ganges above Ghazipur in 800, the Hoangho in 1460, the Rhone in 1500, the Danube in 6800, the Po in 750. Probably therefore we may take the case of the Rhone as approximately an average, and this gives us, if not a measure, at any rate a vivid idea of the immense length of time which must have elapsed.

The great plain shows comparatively gentle elevations, which become more marked in the "Prealps," while the inner chains are thrown into the most extreme contortions. In some cases the result of compression has been to push certain strata bodily over others. Such overthrusts also greatly tend to render the relief of the surface independent of the tectonic structure. If there were no overthrusts, if the arches had been flatter and the troughs broader, the causes which have led to the present configuration of the surface would have been much clearer.

The main ranges then are due to compression and folding, the peaks to erosion, and the three main factors in determining the physical geography of Switzerland, have been compression, folding, and denudation.

The present configuration of the surface is indeed mainly the result of denudation, which has produced the greatest effect in the Central portions of the chain. It is probable that the amount which has been removed is nearly equal to that which still remains,[1] and it is certain that not a fragment of the original surface is still in existence, though it must not be inferred that the mountains were at any time so much higher, as elevation and denudation went on together.

This leads us to the consideration whether the Alps are still rising. On this subject we have no absolute proof. The country is now, however, so well mapped that if changes are still

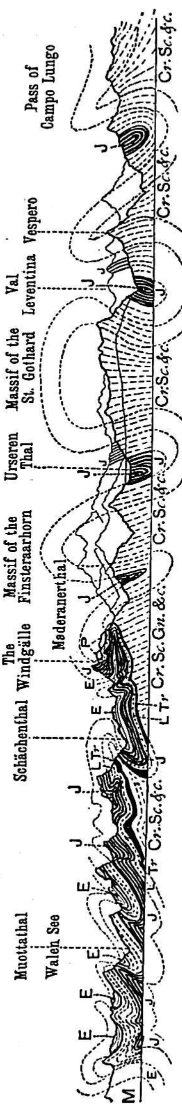


Fig. 26.—Section across the Alps.

[1] Heim, *Beitr. z. Geol. K. d. Schw.*, L. xxv.

going on they must ere long show themselves. It is probable on mechanical and geological grounds that the southern chains were formed first, and the northern ones afterwards in order of succession. It has been shown that the Secondary strata originally covered the whole area, and their removal from the Central massives, except in the deeper folds, is strong evidence of their great age.

There is no proof of any present movement in this Central district. On the other hand slight earthquakes are common in Switzerland; more than 1000 have been recorded during the last 150 years, and no doubt many more have passed unnoticed. This appears to indicate that the forces which have raised the Alps are perhaps not entirely spent, and that slow movements may be still in progress along the flanks of the mountains.[1]

Many of these earthquakes are very local and as a rule not deep seated, at a depth of not more than from 15,000 to 20,000 metres.

Even however in the Central Alps there is still some evidence of continual strain. When the tunnels were being pierced for the St. Gotthard line, and especially the Wattinger tunnel near Wasen, slight explosions were often heard, and blocks of rock were thrown down on the workmen. These generally came from the roof, but sometimes from the sides, and

[1] Heim, *Mech. d. Gebirgsb.*, vol. ii.

eventually it was found necessary to case the interior of the tunnel.[1] These phenomena, however, may have been only due to the great pressure.

The American geologists, and especially Dana, have pointed out that folded mountains are not as a rule symmetrical but one-sided. Suess[2] has extended this to Switzerland, and indeed to folded mountains generally. It is remarkable that in all the European mountain systems—the Alps, Appennines, Jura, Carpathians, Hungarian Mountains, etc., the outer side of the curve presents a succession of folds which gradually diminish in intensity, while the inner side terminates in an immense fold, the anticlinal, or arch of which, in the case of Switzerland, constitutes the outer crest of the Alps, while the synclinal, or area of depression, has given rise to the great valley of the Po, which appears to be an area of sinking.

The Jura rises gently from the north-west, and culminates in the steep wall which bounds the Central plain of Switzerland.

The Ural Mountains and their continuation, the Islands of Novaya Zemlya, are steep on the eastern side. In fact, the Urals are not so much a chain of mountains, as a tilted surface, with a sudden fracture, and a sunken area to

[1] Baltzer, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.
[2] *Das Antliz der Erde.*

the east.[1] The Indian Ghats again present a very steep side to the sea. The Himalayas which in so many respects resemble the Alps, the Rocky Mountains, the Green Mountains, the Alleghanies, etc., are also one-sided; and South America slopes up from the east to the great wall of the Andes which towers over the Pacific Ocean.

The Alps are a most delightful, but most difficult, study, and although we thus get a clue to the general structure of Switzerland, the whole question is extremely complex, and the strata have been crumpled and folded in the most complicated manner, sometimes completely reversed, so that older rocks have been folded back on younger strata, and even in some cases these folds again refolded.

[1] Suess, *Die Entstehung der Alpen.*

CHAPTER IV

SNOW AND ICE—SNOWFIELDS AND GLACIERS

"Chaque année je me livre à de nouvelles recherches, et en me procurant un genre de jouissance peu connu du reste des hommes, celui de visiter la nature dans quelques-uns de ses plus hauts sanctuaires, je vais lui demander l'initiation dans quelques-uns de ses mystères, croyant qu'elle n'y admet que ceux qui sacrifient tout pour elle et qui rendent des hommages continuel."—Dolomieu, *Journal des Mines*, 1798.

THE height of the snow-line in the Alps differs according to localities and circumstances, but may be taken as being from 2500 to 2800 metres above the sea-level.

The snowfields are very extensive, the expanse of firn being necessarily greater than that of the glacier proceeding from it.

The annual fall of snow gives rise to a kind of stratification, which however gradually disappears. The action of the wind tends, on the whole, to level the surface, leaving however many gentle undulations, and heaping up the snow in crests and ridges. Here it often forms cornices, which on the mountains sometimes project several feet. I shall never forget my sensations, when standing with Tyndall on, as I supposed, the solid summit of the Galenstock, he struck his alpenstock into the snow, and I found that we were only supported on such a cornice projecting over a deep abyss.

When the snow falls at a temperature of 0°-12°, it assumes the form of stars or eight-sided crystals.

The region affected by glacial action may be divided into three parts:—

1. The firn or Névé.
2. The glacier.
3. The region of deposit.

The Firn or Névé

The snow which falls in the higher Alpine regions, by degrees loses its crystalline form, becomes granular, and is known as Névé or Firn. It can be distinguished at a glance from recent snow by being less brilliantly white, partly because it contains less air, partly because the particles of meteoric and other dust give it a lightly yellowish, gray, or even brownish tinge. Sometimes it is in patches quite red. This is generally due to the presence of a minute alga (Sphærella nivalis). There are, however, several other minute organisms, plants, Infusoria and Rotifera (Philodina roseola) of a red or brownish color. The firn is generally firm. When the temperature is low, it becomes quite hard; except on hot days the foot sinks but little into it; usually it remains dry. The water which results from melting sinks into it, and freezes the snow below into a solid mass, which has a more or less stratified appearance, each yearly deposit forming a layer from one to three feet in thickness, which can sometimes be traced even to the lower end of the glacier. The firn attains in many places a great depth. Agassiz estimated that of the Aar glacier at 460 metres.[1] It moves slowly downwards, and when its upper end terminates against a rock wall, which of course retains its position, a deep gap is formed in spring, known as a Bergschrund, which widens during the summer and autumn, gradually fills up in winter, and reappears the next year.

It is impossible to give any idea in words of the beauty of these high snowfields. The gently curving surfaces, which break with abrupt edges into dark abysses, or sink gently to soft depressions, or meet one another in ridges, the delicate shadows in the curved hollows, the lines of light on the crests, the suggestion of easy movement in the forms, with the sensation of complete repose to the

[1] *Système Glaciaire.*

eye, the snowy white with an occasional tinge of the most delicate pink, make up a scene of which no picture or photograph can give more than a very inadequate impression, and form an almost irresistible attraction to all true lovers of nature.

The firn would accumulate and increase in thickness indefinitely if it were not removed, (1) by melting and evaporation, (2) by avalanches, and (3) by slow descent into the valley.

AVALANCHES

Avalanches may be divided into two principal classes; dust avalanches, and ground avalanches.

Dust avalanches generally occur after heavy snowfalls and in still weather, because the snow accumulates on steep slopes until it finally gives way; first in one place and then in another; first slowly, then more rapidly, until at last it rushes down with a noise like thunder.

The falling mass of snow compresses the air, and makes a violent wind, which often does more mischief than the actual avalanche itself. A great part of the snow rests at the foot of the declivity from which it falls, but a part is caught up by the wind and carried to a considerable distance. Such avalanches fall irregularly, as they depend on a variety of circumstances; they cannot therefore be foreseen, and do much damage, often killing even wild animals.

Ground avalanches occur generally in spring, when the snow is thawing. The water runs off under the snow, which thus becomes hollow, only touching the ground in places. A slight shock is sufficient to set it in motion, and it tears away down to the ground, which it leaves exposed. Such avalanches depend therefore on the configuration of the surface, and are in consequence comparatively regular. In many cases they follow the same course year after year. In these tracks, trees cannot grow, but only grass or low bushes.

The front part of the avalanche of course first begins to slacken its speed. The part behind then presses on it, and often pushes over it. Those who have been enveloped in an avalanche all agree, that during the motion they could move with comparative freedom, then at the moment of stopping came extreme pressure, and they found themselves suddenly encased in solid ice. Pressure had caused the particles to freeze suddenly.

Avalanches are often looked on as isolated and exceptional phenomena. This is quite a mistake. They are an important factor in Alpine life. The amount of snow which they bring down is enormous. Coaz[1] estimates it in certain districts as equal to 1 metre of snow over the whole district. Without them the higher Alps would be colder, the lower regions hotter and drier. The snow-line would come down lower, many beautiful Alps would be covered with perpetual snow, the glaciers would increase, the climate become more severe, the mountains less habitable. To appreciate the importance of avalanches one must ascend the mountains on a warm day in spring. From every cliff, in every gorge we hear them thundering down all round us. They descend on all sides like hundreds of waterfalls, sometimes in a silver thread, sometimes like a broad cataract. The mountain seems to be shaking off its mantle of snow.

However destructive then they may be at times, avalanches are on the whole a blessing.[2]

Glaciers

By the slow action of pressure, and the percolation of water, which freezes as it descends, the firn passes gradually into ice. In cool and snowy summers the thickness of the layer of firn increases. It is deepest in the higher regions, and thins out gradu-

[1] *Die Lawinen in den Schweizeralpen*, Bern, 1881.
[2] Heim, *Gletscherkunde*.

ally, until at length ice appears on the actual surface, and the firn passes into a glacier.

Glaciers are in fact rivers of ice, which indeed sometimes widen out into lakes. Glacier ice differs considerably from firn ice, and the molecular process by which the one passes into the other is not yet thoroughly understood. Again, if a piece of ice from a lake is melted in warm air the surface gradually liquefies and the whole remains clear; on the contrary, a piece of compact glacier ice from the deeper part of a glacier if similarly treated behaves very differently; a number of capillary cracks appear, which become more and more evident, and gradually the ice breaks up into irregular, angular, crystalline fragments. These are known as the "grains du glacier" or "Gletscherkorn," and were first described by Hugi.[1] They increase gradually in size, but how this growth takes place, and whether they are derived from the granules of the firn, is still doubtful. When the firn passes into the glacier they may be about $\frac{1}{4}$ inch across; in the middle part of a large glacier about the size of a walnut, and at the end 4 or even 6 inches in diameter. Those at the end of the Rhone Glacier vary much in size, but the majority are under an inch across.

In some cases they are tolerably uniform in size, in others large and small are mixed

[1] *Das Wesen der Gletscher*, 1842.

together. On any clean surface of glacier ice they are easily visible, as for instance in the ice tunnel which is so often cut at the end of glaciers. Their surfaces present a series of fine parallel striæ, first noticed by Forel. Glacier ice then may be said to be a granular aggregate of ice crystals. By alternately warming and cooling snow, and saturating it repeatedly with water, Forel found that he produced an ice very similar in structure to that of glaciers. There seems no doubt that this structure considerably facilitates the movements of glaciers.[1]

Glaciers are generally higher in the middle, and slope down at the two sides owing to the warmth reflected from the rocks. When the valley runs north and south the two sides are equally affected in this respect; but when the direction is east to west or west to east the northern side is most inclined because the rocks lie more in the sun, while those to the south are more in the shade.

Movement of Glaciers

Rendu, afterwards Bishop of Annecy, in 1841 first stated clearly the similarity between the movements of a river and those of a glacier.

Subsequent observations have confirmed

[1] Heim, *Gletscherkunde.*

Rendu's statements. In fact the glacier may be said really to flow, though of course very slowly.

The movement of a glacier resembles that of a true river, not only generally, but in many details; the centre moves more quickly than the sides; where the course curves, the convex half moves more quickly than the concave, and the surface more quickly than the deeper portions. The movement is more rapid, indeed some three times more quick, in summer than in winter.

The first detailed observations on the movements of glaciers were made independently and almost simultaneously by Agassiz on the Unter-Aar glacier, and by Forbes on the Mer de Glace.

The yearly motion of the Swiss glaciers is estimated at from 50 to 130, or in some exceptional cases even 300 metres. The rapidity differs however considerably, not only in different glaciers, but in different parts of the same glacier; in different years, and different times of year. The remains of Dr. Hamel's guides, who perished in a crevasse on the Grand Plateau (Mont Blanc) on 20th August 1820, were found in 1861 near the lower end of the Glacier des Boissons, having moved 2800 metres in forty-one years, or nearly at the rate of 70 metres a year.

It has been calculated that a particle of ice would take at least 250 years to descend from the Strahleck to the lower end of the Unter-Aar Glacier; from the summit of the Jungfrau to the end of the Aletsch Glacier about 500 years.

During the Middle Ages the Swiss glaciers appear on the whole to have been increasing in size, and to have reached a maximum about the year 1820. After that they retreated till about 1840, when they again advanced until 1850-60, since which time they have greatly diminished, though some are now again commencing to advance. Those of northern Europe appear to be also increasing.[1] It is, of course, impossible to make any decided forecast as to the future.

Cause of Movement

But why do glaciers descend?

Scheuchzer in 1705 suggested that the water in the fissures of the glaciers, freezing there and expanding as it froze, was the power which urged them forwards. Altmann and Grüner in 1760 endeavoured to explain it by supposing that the glaciers slid over their beds; and no doubt they do so to some extent, but this is quite a subordinate form of movement. Bordier regarded the ice of glaciers "not as

[1] Heim, *Gletscherkunde*.

a mass entirely rigid and immobile, but as a heap of coagulated matter or as softened wax, flexible and ductile to a certain point." This, the "Viscous" theory, was afterwards most ably advocated by Forbes. No doubt the glacier moves as a viscous body would; but the ice, far from being viscous, is extremely brittle. Crevasses begin as narrow cracks which may be traced for hundreds of yards: a slight difference of inclination of the bed will split the ice from top to bottom. It is, in fact, deficient in that power of extension, which is of the essence of a viscous substance.

The explanation now generally adopted is that which we owe mainly to Tyndall. Faraday in 1850 observed, that when two pieces of thawing ice are placed together they freeze at the point of contact. Most men would have passed over this little observation almost without a thought, or with a mere feeling of temporary surprise. Eminent authorities have differed in the explanation of the fact, but into this part of the question I need not now enter. Sir Joseph Hooker suggested the term "Regelation," by which it is now generally known, and Tyndall has applied it to explain the motion of glaciers.

Place a number of fragments of ice in a basin of water, and they will freeze together wherever they touch. Again, a mass of ice placed in a mould and subjected to pressure breaks in pieces, but as the pieces reunite by regelation they assume the form of the mould, and by a suitable mould the ice may be forced to assume any given form. The Alpine valleys are such moulds. When subject to tension, the ice breaks and crevasses are formed, but under pressure it freezes together again, and thus preserves its continuity.

Professor Helmholtz in his scientific lectures sums up the question in these words—"I do not doubt that Tyndall has assigned the essential and principal cause of glacier-motion, in referring it to fracture and regelation." Heim, however, does not regard the problem as being yet by any means solved.[1] He points out that, as in the case of water, a large glacier moves under similar conditions more rapidly than a small one. Many bodies will in small dimensions retain their form, which in larger masses would be unable to support their own weight. A small clay figure will stand where a life-sized model will require support.

Sealing-wax breaks under tension like ice, but under even slight pressure gradually modifies its form. Prof. Heim is convinced that if a mass of lead, corresponding to a glacier, could be placed in a Swiss valley, it would move to a great extent like a glacier. The size of a glacier is therefore an important factor in the question, and throws light on the more

[1] Heim, *Gletscherkunde.*

rapid movement of the greater glaciers, even when the inclination of the bed is but slight. In Heim's opinion then the weight of the ice is sufficient to account for movement, though the character of the movement and the condition of the glacier is due to fracture and regelation. He sums it up in the statement that gravity is the moving force, and the glacier grains the prevailing mechanical units of movement.

Crevasses

The rigidity of ice is well shown by the existence of crevasses. They may be divided into three classes:—

1. Marginal.
2. Transverse.
3. Longitudinal.

The sides of most glaciers are fissured even when the centre is compact. The crevasses do not run in the direction of the glacier, but obliquely to it, enclosing an angle of about 45° (Fig. 29, *m m*) and pointing *upwards*, giving an impression that the centre of the glacier is left behind by the quicker motion of the sides. This was indeed supposed to be the cause, until Agassiz and Forbes proved that, on the contrary, the centre moved most rapidly. Hopkins first showed that the obliquity of the lateral crevasses necessarily followed from the quicker movement of the centre.

Tyndall gives the following illustration :— "Let *A C*, in the annexed figure, be one side of the glacier, and *B D* the other ; and let the direction of the motion be that indicated by the arrow. Let *S T* be a transverse slice of the glacier, taken straight across it, say to-day. A few days or weeks hence this slice will have been carried down, and because the centre

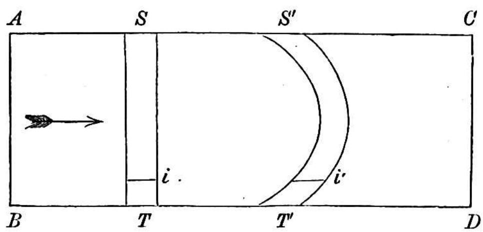


FIG. 27.

moves more quickly than the sides it will not remain straight, but will bend into the form *S′ T′*.

"Suppose *T i* to be a small square of the original slice near the side of the glacier. In its new position the square will be distorted to the lozenge-shaped figure *T′ i′*. Fix your attention upon the diagonal *T i* of the square ; in the lower position this diagonal, *if the ice could stretch*, would be lengthened to *T′ i′*. But the ice does not stretch, it breaks, and we have a crevasse formed at right angles to $T' i'$. The mere inspection of the diagram will assure you that the crevasse will point obliquely *upward*."

Marginal crevasses then arise from the movement of the glacier itself; transverse and longitudinal crevasses are caused by the form of the valley. If the inclination of the bed of a glacier increases, even if the difference be but slight, the ice is strained, and, being incapable of extension, breaks across. Each fresh portion as it passes the brow snaps off in turn, and thus we have a succession of transverse crevasses. In some cases these unite with the transverse fissures, thus forming great curved crevasses, stretching right across the glacier, and of course with the convexity upwards.

Longitudinal crevasses occur wherever a glacier issues from a comparatively narrow defile into a wider plain. The difference of inclination checks its descent; it is pushed from behind, and having room to expand it widens, and in doing so longitudinal crevasses are formed.

The sides of crevasses are of a brilliant blue, and often look as if they were cut out of a mass of beryl. The mountaineers have a tradition that glaciers will tolerate no impurity, and though this is not of course a correct way of stating the question, as a matter of fact the ice is of great purity.

Veined Structure

Glacier ice very often looks as if it had been carefully and regularly raked. It presents innumerable veins or bands of beautifully blue clear ice, running through the general mass, which is rendered whitish by the presence of

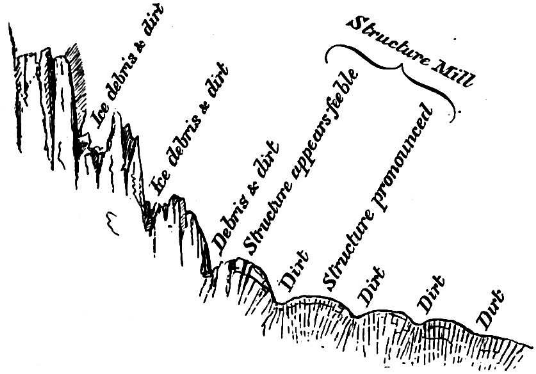


Fig. 28.—Section of Icefall, and Glacier below it, showing origin of Veined Structure.

innumerable minute air-bubbles. The blue plates are more or less lenticular in structure, sometimes a few inches sometimes many yards in length, but at length gradually fade away.

The whole surface of the glacier in such parts is lined with little grooves and ridges, the more solid blue veins projecting somewhat beyond the whiter ice. This structure is very common, though presenting different degrees of perfection in different glaciers, and different parts of the same glacier. It is rendered the more conspicuous, because the fine particles of dirt are naturally blown, and washed into the furrows. The veins are often oblique, in many cases transverse, in some longitudinal, and in others vary in different parts of the glacier.

Here also we owe, I think, the true explanation to Tyndall. We will begin with the oblique veins, which are most marked at the sides, and fade away towards the

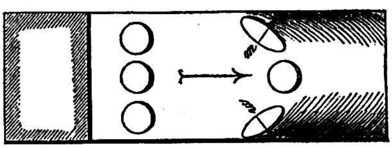


FIG. 29.

centre of the glacier. Tyndall points out that if a plastic substance, such as mud, be allowed to flow down a sloping canal, the lateral portions, being held back by the sides, will be outstripped by the centre. Now if three circles (Fig. 29) be stamped on the mud-stream, the central one will retain its form, but the two lateral ones will gradually elongate. The shorter axis in *m m* of each oval is a line of pressure, the longer is a line of strain, consequently along the line *m m*, or across the tension, we have, as already explained, the marginal crevasses; while across the line, or perpendicular to the pressure, we have the veined structure, which is in fact a form of cleavage. Indeed, tension and pressure go together, the one acting at right angles to

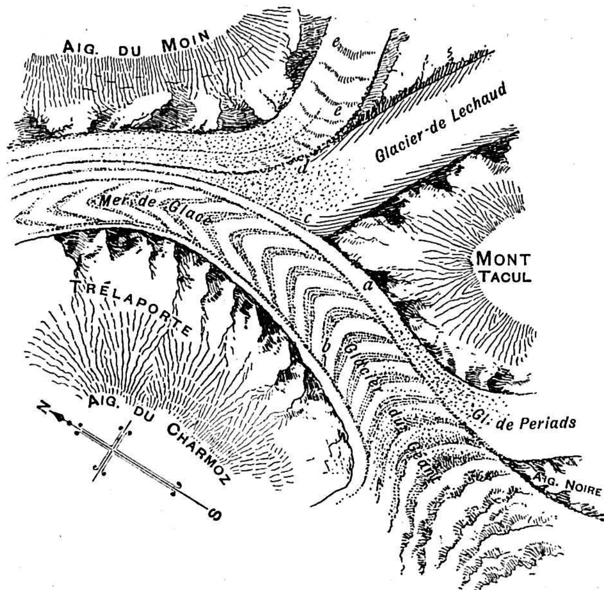


FIG. 30.—Sketch Map of the Mer de Glace.

the other. Passing to the cases of transverse veining, we find if we walk up a glacier presenting this structure that we eventually come to an ice-fall or cascade. At the foot of the fall the ice is compressed, and this gives rise to transverse veining. Longitudinal veining in the same manner arises when two glaciers meet, as for instance the Talèfre and the Léchaud (Fig. 30), where we have transverse pressure and in consequence longitudinal veining. How great must be the pressure in such cases we can faintly realise if we bear in mind that the glaciers which unite to form the great Gorner Glacier have a width of 5200 metres which is compressed to 1000 and further on to 500 metres.

The pressure acts on the ice in two ways—Firstly, in the same manner as it produces lamination in rocks; and secondly, by partially liquefying the ice, thus facilitating the escape of the air-bubbles, which causes its whitish appearance.

Liquid Disks

The Solar beams also form innumerable liquid disks. As the water occupies less space than the ice each disk is accompanied by a small vacuum, which shines like silver, and is often taken for an air-bubble.

Dirtbands

If we look down on the Mer de Glace we see (Fig. 30) a series of gray, curved, or bent bands, which follow each other in succession from Trélaporte downwards.

These "dirtbands" have their origin at the ice cascade upon the Glacier du Géant. The glacier is broken at the summit of the ice-fall (Fig. 28), and descends the declivity in a series of transverse ridges. Dust, etc., gradually accumulates in the hollows, and though the ridges are by degrees melted away and finally disappear, the dirt remains, and forms the bands. They are therefore quite superficial. Similar bands occur on other glaciers with ice cascades, and as many as thirty to forty may sometimes be traced.

Moulins

At night and in winter the glaciers are solemn and silent, but on warm days they are enlivened by innumerable rills of water. Sooner or later these streams reach a crack, down which they rush, and which they gradually form into a deep shaft. These are known as glacier mills or Moulins. Of course the crack moves down with the glacier, but the same cause produces a new crack, so that the process repeats itself over and over again, at approximately the same place. A succession of forsaken Moulins is thus formed. Moulins are often very deep. Desor sounded one on the Finster-Aar glacier which had a depth of 232 metres.

The so-called Giants' caldrons, which will be described further on, are sometimes regarded as indications of ancient glacial action. It is probable that in the case of the so-called "glacier garden" at Lucerne this is so; but as a general rule they were probably formed by river action.

In the larger glaciers most of the subglacial rivulets unite under the glacier and flow out at the end in a stream, often under a beautiful blue flat arch generally from 1 to 3 but sometimes even 30 metres in height. In many cases it is possible to enter them for some distance, and galleries are often cut. The ice is a splendid blue, the surface takes a number of gentle curves, and when the light from outside is reflected from the surfaces, it assumes by complementary action a delicate tint of pink.

Moraines[1]

The mountain sides which surround glaciers shower down on them fragments, and sometimes immense masses, of rock, which gradually accumulate at the sides and at the end, and are known as "Moraines." When two glaciers meet, a "medial" moraine is formed by the

[1] The word "Moraine" was adopted by Charpentier from the local name used in the Valais, and has now become general.

union of two "lateral" moraines (Fig. 30), while the matter carried along under the glacier is known as "ground Moraine." However many glaciers may unite, the moraines keep themselves distinct, and may often be seen for miles stretching up the glacier side by side.

Even from a distance we may often see by the color that different moraines, and the two sides of a medial moraine, are composed of different rocks. On the Aar glacier the left half of the medial moraine is composed of dark micaceous Gneiss and Mica Schist; the right half of white Granite. The right lateral moraine of the Puntaiglas glacier, on the south of the Tödi group, is made up of dark greenish Syenite and Granite, the first medial moraine is of titaniferous Syenite, then comes a second of yellowish red Röthidolomite with some Dogger; then several of bluish black Hochgebirgskalk, and lastly the left moraine is of Puntaiglas Granite, and various sedimentary rocks from Verrucano to Eocene.[1] The Baltora glacier in the Hindu Kush has no less than fifteen moraines of different colors. The different moraines do not mix; and fragments from one side, even of the same moraine, never pass to the other, but move down with the ice, in the same relative positions.

[1] Heim, *Gletscherkunde*, p. 348.

The glacier often rests directly on the solid rock, but in many places there is a layer of clay and stones, to which Ch. Martins gave the name of "ground moraine," and if the underlying rock is examined it will be found to be more or less polished and striated. The importance of the ground moraine was first pointed out by Martins.[1] The pressure of the glacier on its bed must be very great. On the Aletsch glacier it has been calculated to be as much as 4 tons to the square decimeter; under the Arctic glaciers it must be much greater. In the winter of 1844 some poles of timber were dropped under the edge of the Aar glacier, in the following year they were found to be crushed to small fragments. Blocks of stone are gradually ground down and reduced to glacial mud. This is so fine that it remains a long time in suspension in water, and gives their milky colour to glacial streams. The ground moraine is no doubt formed in some measure from surface blocks which have found their way through crevasses, and have to a great extent been crushed and reduced to powder; but as ground moraines occur under ice-sheets, such as that of Greenland, when there are scarcely any surface blocks, it is clear that the material is partly derived from the underlying bed.

At the lower end of the glacier a terminal

[1] *Revue des Deux Mondes*, 1847.

moraine gradually accumulates, which may reach a height of 50, 100, or even 500 metres. They are more or less curved, encircling the lower end of the glacier.

The quantity of debris differs greatly in different glaciers: some, as the Rhone, Turtmann, etc., are comparatively free, while others, as the Zinal and the Smutt, have the lower ends almost entirely covered.

It is difficult to give the actual number of glaciers in Switzerland, because some observers would rank as separate glaciers what others would consider as branches, but the number may be taken as between 1500 and 2000. The total area is about 3500 sq. km.

The mean inclination of large glaciers is from 5° to 8°, falling however even to less than a degree. The hanging glaciers are much steeper.

The greatest thickness of the ice can only be estimated. In one place of the Aar glacier Agassiz found a depth of 260 metres without reaching the bottom. From the configuration of the surface, however, it may safely be calculated that the ice must attain a thickness in places of 400 or even 500 metres. It has been calculated that the ice of the Görner glacier would be enough to build three Londons.

The distance to which a glacier descends depends partly on the extent of the collecting ground, partly on the configuration of the surface. The Görner glacier advances so far on account of the magnitude of the snow-fields above. In 1818 the lower Grindelwald glacier descended to 983 metres above the sea level. In 1870 it had receded to 1080 metres. The lower limit of the Mer de Glace is 1120 metres. In the Eastern Alps, where the climate is more continental and drier, the general limit is from 1800 to 2300 metres.

Ice Tables

Small bodies, such as pebbles, dust, insects, etc., tend to sink into the ice. On the other hand larger stones intercept the heat.

On most glaciers may be seen large stones resting on pillars of ice. These are the so-called Ice tables. If the stone be wide and flat, the pillar may reach a considerable height, for the ice immediately under it, being protected from the rays of the sun, melts less rapidly. The tables are rarely horizontal, but lean to the south, that side being more exposed to the sun. Small stones and sand, on the contrary, absorb the heat and melt the snow beneath them, unless indeed there is a sufficient thickness of sand, in which case they intercept the heat and form cones, sometimes ten or even twenty feet in height.

Medial moraines in the same way tend to

check the melting. That on the Aar glacier rises 20, 40, and even 60 metres above the general surface, and from the summit of the Sidelhorn it gives the impression of a wide black wall separating two white rivers. In Greenland such ice-walls have been known to attain a height of 125 metres.

We can hardly have a better introduction to the study of glaciers than a visit to the Rhone glacier (Frontispiece). The upper part, which is not shown in the figure, is a magnificent and comparatively smooth ice-field. Then comes a sharp descent, where in a river we should have a cascade or series of cascades, and where the ice breaks into a series of solid waves. The crests gradually melt, and as dust and stones collect in the hollows, and the centre of the glacier moves more rapidly than the sides, we have a succession of dirt bands which curve across the glacier.

Below the fall, the bed of the glacier becomes again comparatively flat; the glacier is squeezed out so as to become considerably wider, and as the ice cannot expand it splits into a number of diverging crevasses. This was much more marked when I first visited the glacier in 1861, and when it was much larger than at present.

If we start from the hotel, after crossing the river, at a very short distance we come to a bank of loose sand and stones, some angular, some rounded, which curves across the valley, except where it has been washed away by the river. This is the moraine of 1820, and shows the line at which the glacier stood for some years. The Swiss glaciers generally increased till about 1820, then diminished for some years, increasing again till about 1855-60, since which they have retreated considerably. The moraine of 1856, in the case of the Rhone glacier, forms a well-marked ridge some distance within that of 1820.

From that ridge to the foot of the glacier, the valley is occupied by sand and stones in irregular heaps, some of them smoothed and ground by the glacier. This is especially the case with the larger stones, which show a marked difference on their two sides, that turned towards the glacier being smooth, while the lee side is rough and abrupt. Many of the stones were evidently pushed by the glacier along the valley, and have left a furrow behind them. The Rhone wanders more or less over the flat bottom of the valley, and spreads out the material which has been brought down by the glacier.

Here and there on the glacial deposits lie blocks with fresh angles, totally different in appearance from the rounded blocks borne by the glacier. These have been brought down by avalanches.

Near the glacier are two other small moraines, the outer one that of 1885, the inner of 1893. We know that these moraines were deposited by the glacier, and no one who has seen them can doubt that those farther and farther down the valley have had a similar origin.

The Rhone flows from the foot of the glacier in various and varying streams, but especially at one place near the centre of the face of the glacier, where there is a beautiful blue arch, about 25 metres in height.

In 1874 careful measurements were commenced by the Swiss Alpine Club. At first lines of stones were placed annually at the foot of the glacier, but the river washed them away so much that the present limits are laid down annually on a plan. It is found that just as the glacier advances when we have a succession of cold and snowy years, and diminishes when there have been hot and dry periods; so in each year, even when the glacier is on the whole retreating, it advances in two or three of the winter months. Amongst other means of studying the glacier the Commission have placed lines of stones across it at some distances above the fall. One of these lines was arranged in 1874, the stones painted yellow, and their position carefully marked. When they came to the fall they disappeared for four years, after which some of them again emerged at the surface, and some of the central ones have now reached the lower end of the glacier, which has retreated some yards from the spot at which they were deposited.

As in many of the most accessible glaciers, a gallery has been cut into the ice, and is well worth a visit.

The exquisite curves into which the ice is melted by the eddying currents of air are very lovely. Again, one can easily trace the glacier grains especially if a little ink or other colored fluid is rubbed over the surface of the ice, when it runs down between the grains, marking them out with dark lines. Each grain, moreover, shows very fine lines of crystallisation, which are parallel in each grain, but differ in different grains. The chief attraction, however, is naturally the splendid blue color of the ice, and the lovely pink complementary tints of the reflections from the surface.

CHAPTER V

ON THE FORMER EXTENSION OF GLACIERS

THE present scenery of Switzerland has been much influenced by the former extension of glaciers, and the fertility of the country is greatly enhanced by the materials which they have brought down from the mountains and spread over the low country. Several of the lakes, moreover, which add so much to its beauty, owe their origin to ancient moraines.

The existence of a glacial period and the great former extension of the Swiss glaciers is proved by four lines of evidence, namely :—

1. Moraines and fluvio-glacial deposits.
2. Erratic blocks.
3. Polished and striated surfaces.
4. Animal and vegetable remains belonging to northern species.

GLACIAL DEPOSITS

Glacial deposits may be classed under two heads :—

1. Moraines.

2. Glacial deposits which have been re-arranged by water and may be termed fluvio-glacial.

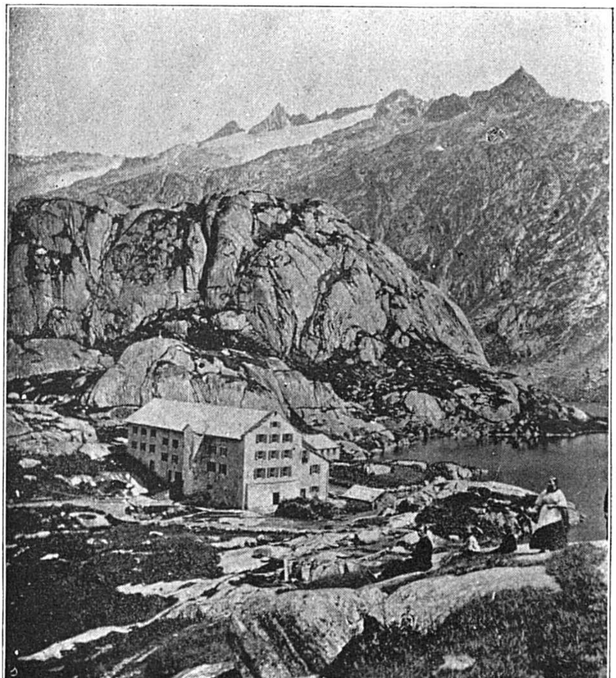


FIG. 31.—View of the Grimsel.

Moraines are characterised by the presence of polished and striated pebbles, intermixed with more or less angular fragments, often coming from a great distance and yet not rolled, irregularly deposited in sand and mud, which, however, is not stratified.

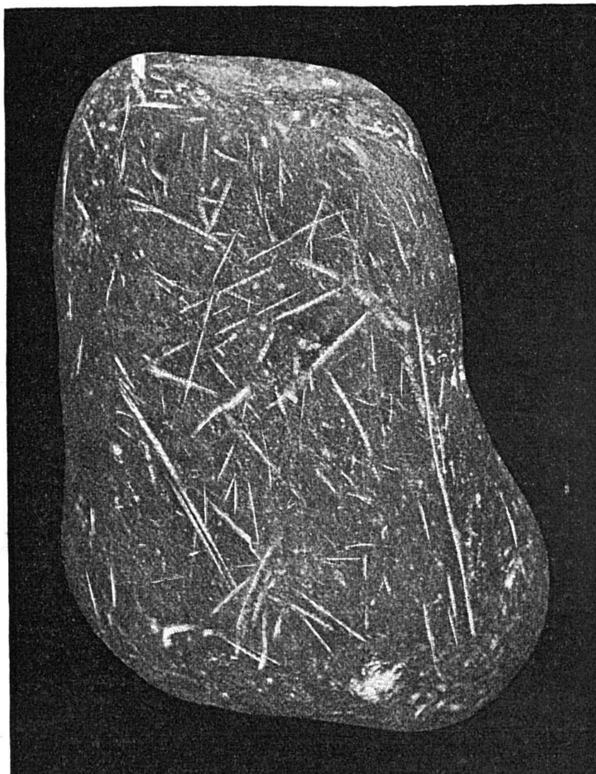


FIG. 32.—Scratched Pebble from the moraine at Zürich.

Fluvio-glacial deposits are composed of the same materials, but more or less rolled, and rearranged by water, like river gravels. They are glacial deposits caught up and carried to a greater or less distance by water.

These two deposits are in intimate relation; they agree in their composition, and differ only as regards stratification. The fluvio-glacial beds, as we come nearer and nearer to their source, are composed of larger and more angular pebbles, while the stratification becomes less and less regular, so that they approximate more and more to the character of true moraine.

The surface of a true glacial deposit is irregular, and presents a succession of hills and valleys, often more or less concentric in outline, and enclosing a central depression (the site of the glacier itself), so that it forms a sort of amphitheatre. See for instance Fig. 33. The Wettingen Feld in the valley of the Limmat is the cone of fluvio-glacial deposits from the ancient moraine of Killwangen.

As glaciers often retreat and then advance again the cone of transition in many cases presents alternations of true morainic and fluvio-glacial strata.

When the glacier retreated, the water occupied the central depression between the ice and the moraine, forming a lake. In most cases, however, it cut by degrees through the moraine, and drained the lake. The streams then wandered over the old glacier bed. That the lake naturally overflowed at the lowest point of the moraine, explains why the outflow is often not in the centre of the valley, and occasionally at some distance from the end of the lake, as for instance, at the Lake of Hallwyl (Fig. 35).

Far down the valleys we find moraines, exactly similar in character to those still being formed along the sides and in front of existing glaciers, and repeated again and again, indicating that glaciers must once have extended far beyond their present areas.

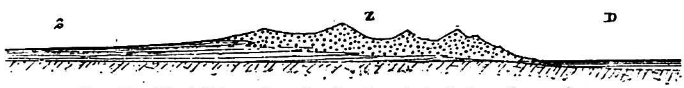


FIG. 33.—Glacial Deposits. *D*, site of ancient glacier; *Z*, moraine; *z*, fluvio-glacial deposits.

The Rhone glacier occupied the Valais, in which are several ancient moraines; it filled the whole basin of the Lake of Geneva; and the high terrace of St. Paul above Evian is a moraine, due to the confluence of the ancient glaciers of the Rhone and Dranse; so is also the promontory of Yvoire. Still further down the valley glacial deposits are found along the Rhone as far as, and even beyond Lyons,[1] and down the Aar to Waldshut.

Fig. 34 represents river terraces and glacial deposits in the valley of the Aar, a short distance above Coblenz.

[1] Falsan and Chantre, *Les Anciens Glaciers du Bassin du Rhône.* 1880.

Passing from the Aar eastwards, in the district of the Wigger, there are important moraines round the Lake of Wauwyl, which was the site of a Lake Village carefully studied by Col. Suter, but is now drained.

In the valley of the Suhr is an important terminal moraine at Stafelbach, another at Triengen, while a third encircles and has given origin to the Lake of Sempach.

In the valley of the Winan there is a

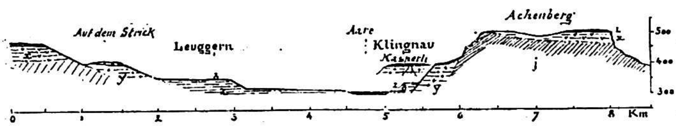


FIG. 34.—Section across the Valley of the Aar above Coblenz. Scale, length 1=100,000; height 1=25,000. *z*, Lower alluvial terrace; *y*, upper alluvium covered by moraines and Löess; *x*, alluvium of the upper plateaux, covered by Löess; *j*, Jurassic strata *in situ*.

terminal moraine at Zezwil and another just above Münster.

In the valley of the Aa, are three groups; firstly, one south of Lenzburg; secondly, at the north end of the Lake of Hallwyl are several moraines (Fig. 35); thirdly, between Schafisheim and Egliswyl are three moraines. the inner one encircling a moss, marked Todtenmoos on the map, through which runs the river Aa. Near Nieder Hallwyl is another semicircular moraine enclosing an area of low ground and the end of the lake. The lateral moraine extends along the hill on both sides

FIG 35.—Map of the country between Lucerne and Aarau.

of the water. The moraines on each side of the water are in parts roughly stratified, and fall away from the lake, having originally sloped no doubt from the great dome of the glacier.

In the valley of the Reuss is perhaps the finest group of all, consisting of five ridges forming an amphitheatre round the little town of Mellingen. The Heiterberg, between the Reuss and the Limmat, is also encircled by one, which reaches a height of no less than 100 metres.

In the valley of the Limmat there is a fine terminal moraine at Killwangen, another below Schlieren, a third at Zürich, and a fourth forms the bank which crosses the Lake at Rapperschwyl. These terminal moraines are connected by lateral moraines running along the sides of the hills, but as we shall presently see, they do not mark the greatest extension of the glaciers. They mark places where the glaciers made a stand during their final retreat.

The moraines on the south of the Alps are even more astonishing. Probably from the steeper slope, and more rapid melting under a southern sun, the ends of the glaciers do not appear to have moved so frequently. Hence the terminal moraines are more concentrated, grander, and higher. They form immense amphitheatres terminating in ridges several hundred feet high, and no one seeing them for the first time would for a moment guess their true nature. The blueness of the sky, moreover, the brilliancy of coloring, the variety and richness of the vegetation, give the moraine scenery of Italy an exquisite beauty with which the north can scarcely vie. Each great valley opening on the plain of Lombardy has its own moraine. At the lower end of the Lago Maggiore at Sesto-Calende are three enormous concentric moraines.[1] Those of the Lake of Garda are perhaps the largest. They form a series of concentric hills, and attain a height of 300 metres, but those at Ivrea, at the opening of the Val d'Aosta, due to the great glacier proceeding from the south flanks of the Mont Blanc range, are the highest and most imposing. They form an amphitheatre round Ivrea. That on the east, known as the "Serra," runs in nearly a straight line from Andrate to Cavaglio, is twenty miles long, and has a height above the valley of 500 metres. The summit line is very uniform. On the outer or eastern side of the great moraine are several other minor ridges. At the right a similar, but less elevated moraine, stretches from Brosso to Strambinello, but it is not so conspicuous, as it rests against the side of the mountain.

[1] Martins and Gastaldi, "Essai sur les terrains sup. de la Vallée du Po," *Bull. Soc. Géol. de France*, 1850.

From Strambinello to Cavaglio it forms a great semicircle which once probably enclosed a lake, now represented by the Lago di Viverone, Lago di Candia, and some smaller pools. It is nearly bisected by the Dora Baltea. In fact, it is characteristic of the Italian valleys that the surface is comparatively low where the valley debouches into the plain, and then gradually rises towards the Po, forming an amphitheatre whose encircling wall is the outer moraine.[1]

At several places on the south flank of the Alps, morainic masses are more or less intercalated with younger marine deposits, closely resembling the submarine moraines of the Polar regions, and the Boulder Clay of England and Scotland.

The older moraines are, moreover, less abrupt, and the slopes are more gentle.

Erratic Blocks

The second class of evidence proving the former extension of glaciers is that presented by erratic blocks, which are often of great size, unrounded, and which have come from a great distance. Several of these are so remarkable that they have struck the imagination of the peasantry, have been attributed to superhuman agency, and have received special names, such

[1] Penck, *Vergletscherung der Deutschen Alpen.*

as the "Pierres de Niton" in the lake near Geneva, so called from a tradition that in Roman times sacrifices were offered upon them to Neptune. The "Pierre de Crans" near Nyon, is 73 feet long and 20 high.

The "Pierre à Bot," near Neuchâtel, at a height of 2200 feet, is 62 feet in length, 48 in breadth, and 40 feet high. It is of Protogine, and probably came from the St. Bernard.

Other celebrated erratic blocks are the "Ploughstone," which rises 60 feet above the ground between Erlenbach and Wetzweil, and contains over 72,000 cubic feet of stone; the Bloc du Trésor near Orsières with a cubic content of 100,000 feet; the Monster block at Montet, near Devent, 160,000; and the largest of all is, I believe, a mass of Serpentine on the Monte Moro, near the Mattmark See, which measures 240,000 cubic feet. These enormous blocks are of course exceptional, but smaller ones are innumerable. In some localities are immense groups—for instance on the hill of Montet, near Devent, at Orsières in the valley of the Dranse D'Entremont above Martigny, at Arpille on the north side of the valley of the Rhone opposite Martigny, and, still further away from the mountains, the entire south slope of the Jura is strewn with Granite blocks. "Between Moliers, Travers, and Fleurier," says De Luc, "there are as many blocks of primitive rock as if one was in the high Alps."[1]

One of the most remarkable groups is at Monthey, overlooking the valley of the Rhone below St. Maurice. We have here, says Forbes, "a belt or band of blocks—poised, as it were, on a mountain side, it may be five hundred feet above the alluvial flat through which the Rhone winds below. This belt has no great vertical height, but extends for miles—yes, for miles—along the mountain side, composed of blocks of Granite of thirty, forty, fifty, and sixty feet in the side, not a few, but by hundreds, fantastically balanced on the angles of one another, their gray weather-beaten tops standing out in prominent relief from the verdant slopes of secondary formation on which they rest. For three or four miles there is a path, preserving nearly the same level, leading amidst the gnarled stems of ancient chestnut trees which struggle round and among the pile of blocks, which leaves them barely room to grow: so that numberless combinations of wood and rock are formed where a landscape-painter might spend days in study and enjoyment."[2]

As already mentioned, these blocks have come from a great distance. No similar rock occurs in the neighbourhood, and it is often

[1] Agassiz, *Essai sur les Glaciers.*
[2] Forbes, *Travels through the Alps of Savoy.*

possible to determine the locality from which they have been derived.

For instance, near the Katzensee is a block consisting of a peculiar variety of Granite only known to occur at Ponteljes-Tobel above Trons in the valley of the Rhine. Many blocks of the same rock occur on the right bank of the Lake of Zürich, and they can be followed all the way to their source. Not one occurs to the left of the lake. This could hardly be the case on any other theory than that of transport by a glacier. Again, the "Ploughstone" already mentioned agrees with the fine-grained Melaphyre of the Gandstock in the middle of the Canton of Glarus.

The block of Steinhof near Soleure, which measures 65,000 feet, is probably from the Val de Bagnes.

The Pierre à Bot, as already mentioned, is of Protogine, and has come from the St. Bernard.

It is probable that the ancient glaciers moved more rapidly than their comparatively diminutive descendants of the present day; but at the existing rate of movement the Pierre à Bot would have taken 1000 years to travel from its original home on the chain of Mont Blanc to its present site near Neuchâtel; and the Granite blocks of Seeberg would have spent 2000 years on their long journey.

It is evident that these blocks cannot have been brought by water, both on account of the immense velocity which would have been required to transport such enormous weights, and because, amongst other reasons, their angles are as a rule sharp and unrounded.

Their presence is often attributed by the peasantry to supernatural agency, and many legends grew up round them. Favre[1] records a remark made to him by a peasant with reference to a great block of Protogine near Sapey. "'Jamais,' disait-ils, 'on a vu une si belle pierre: elle est tout entière, rien de cassé. Et puis, elle est si tranquille. On ne sait pas si les pierres grandissent; mais, il y a 15 ans, je pouvais monter dessus, à présent je ne sais comment cela se fait, mais je n'y puis grimper.'"

Playfair, in 1802, appears to have been the first to compare these erratics with moraines, and to suggest that they were transported by glaciers.

"For the moving of the large masses of rock," says Prof. Playfair,[2] "the most powerful agents without doubt which nature employs are the glaciers, those lakes or rivers of ice which are formed in the highest valleys of the Alps, and other mountains of the first order. These great masses are in perpetual motion, together with the innumerable fragments of rock with which they are loaded. These fragments they gradually transport to

[1] *Rech. Géol.*, vol. i.

[2] *Illustrations of the Huttonian Theory*, vol. i.

their utmost boundaries, where a formidable wall ascertains the magnitude, and attests the force, of the great engine by which it was erected." The immense quantity and size of the rocks thus transported have been remarked with astonishment by every observer. Perraudin, a Chamois hunter of the Val de Bagnes, subsequently but independently made the same suggestion to Charpentier. It also occurred to, and was proposed in more detail by Venetz, and at length in 1829 worked out by Charpentier with masterly ability. Agassiz compared the Swiss phenomena with those presented in the nòrth of Europe, and showed that in both cases the country was covered by a sea of ice, from which the highest summits alone emerged.

Charpentier,[1] and subsequently Guyot,[2] traced the course of the erratic blocks, and pointed out that as we proceed from the place of origin they spread as it were in a fan, and that those from one district do not overlap those from another, as would be the case if they had been distributed by rivers or icebergs: for instance, those of the West Jura come from Mont Blanc and from the Valais, those of the Bernese Jura from the Bernese Oberland, and those of Argovie from the eastern cantons and the

[1] *Essai sur les Glaciers.*
[2] *Bull. Soc. Sci. Nat. Neuchâtel*, vol. i.

Rhine.[1] Not only are the blocks from each drainage area kept separate, but even, as a rule, those from the two sides of the same valley. I say as a rule, because in some few cases the glaciers appear to have varied in relative dimensions, one encroaching for a time on another, and in its turn being driven back. This however only applies to some few exceptional areas, as for instance between the glaciers of the Linth and the Reuss.

Again, the erratic blocks are specially numerous on the summits and slopes of hills, much more than in valleys: they are not sorted in sizes, but even the largest are found perhaps 50, or even 100, miles from their original site. The smaller blocks are often polished and striated, like those on existing glaciers.

For these and other reasons there can be no doubt that they have been carried by glaciers to their present position.

These great blocks, however, imposing as they are, are yet as nothing to the mass of gravel, sand, and mud brought down by the glaciers, carried over intervening ridges and across lakes, and spread over the whole of Switzerland.

The erratic blocks are unfortunately rapidly disappearing, as they are much in demand for building and other purposes. Some of the most remarkable have, however, happily

[1] Agassiz, *Etudes sur les Glaciers.*

been secured, and will be preserved by the Swiss Scientific Societies.

Considering the immense magnitude of the moraines and the enormous number of erratic blocks, it is evident that the glacial period must have been of very long duration.

Polished and Striated Surfaces—Roches Moutonnées

A third class of evidence is that furnished by polished and scratched rock surfaces, which of course are best preserved when the material is hardest. The rocks are sometimes polished like a looking-glass. Such surfaces occur under and round existing glaciers, where there can be no doubt that they are the work of the ice, or rather of the stones contained in it. Fig. 31 is a photograph of the Hospice of the Grimsel, showing a remarkable case of such glaciated rocks. Similar surfaces occur, however, far away from the present glaciers and even in countries where none exist. The gray rounded bosses (Fig. 31) were termed by De Saussure "Roches Moutonnées," from their frizzled surface. The term has been generally adopted, mainly perhaps because at a distance they look not unlike sheep's backs. Smooth rock surfaces may often be seen at the sides of valleys, sometimes at a great height—many hundred or even some thousands of feet above the present river, and far away from the present glaciers, as, for instance, on the slopes of the Jura. They are specially well developed where from a turn in the valley, or any other cause, the ice met with most resistance. The rocks at Martigny are a very fine example.

They do not, however, generally rise to the uppermost ridges, which have therefore (Fig. 37) quite a different character.

De Saussure first noticed the prevalence in the Alps of smooth, and even polished rock surfaces, but he did not suggest any explanation. Charpentier pointed out that they were

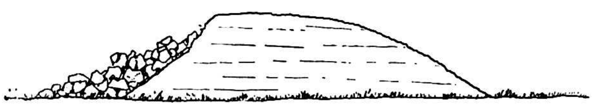


FIG. 36.—Diagram of Crag and Tail.

due to the action of glaciers. Running water also smooths rocks, but it is almost always easy to distinguish the action of water from that of ice. In the first place, the "Roches Moutonnées" are generally marked by striæ, running in the direction of the valley, and due to small stones contained in the ice, and frozen earth. Again, water acts most energetically in the hollows, ice especially on any projecting surface, so that in water-worn surfaces the curves are concave, while on "roches moutonnées" they are convex. The action of water is also much more irregular than that due to ice.

De Saussure was also long ago struck by the fact that at Chamouni, in the valley of the Aar, and elsewhere, the higher rocks were angular and pointed, while the sides of the valley below were rounded and smooth, but he did not suggest any explanation. Hugi observed the same fact, and attributed it to a difference in the character of the rocks." Desor,[1] however, in 1841 ascended the Juchli-

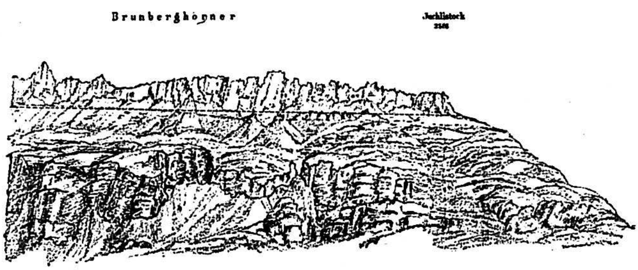


FIG. 37.—View of the Brunberghörner and the Juchlistock, near the Grimsel, showing the upper limit of glacial action.

berg, where the contrast is well marked, and satisfied himself that the Granite was absolutely the same. He observed, moreover, that on the smooth Granite, especially on the upper part, were many blocks of Gneiss, brought from the Mieselen and the Ewig-schneehorn. These blocks could only have been brought by glaciers, and he concluded, therefore, that the smooth polished surfaces were due to the action of the glacier, and that

[1] Desor, *Gebirgsbau*.

the rough, angular upper parts were those which had stood above the level of the ice.

Such polished surfaces are by no means confined to the Alpine valleys. Where suitable rocks occur, they are found throughout the central plain and on the Jura, when they are often very well developed, and known locally as Laves. The upper level of the rounded rocks falls with the valley.

On the shores of Norway and Sweden such glaciated surfaces can even be traced under the sea, especially when the water is free from sand. The scratches follow the general direction of the valley, the polished surfaces are on the weather side, and the lee side is the most abrupt, as in Fig. 36. A good example of such smoothed rocks may be seen just in front of the great Hotel at the Maloja.

Giants' Caldrons

Giants' caldrons are sometimes assumed to be evidence of ancient glacier action. Those at Lucerne and at the Maloja probably are so, but in other cases similar hollows have been produced by river action.

Evidence derived from the Flora and Fauna

Another class of evidence is that derived from botany and zoology. Many of the plants now occupying the Swiss mountains are indigenous to the Arctic regions. They could not under existing circumstances cross the intervening plains, but must have occupied them when the climate was colder than it is now, and been driven up into the mountains, like the Marmot and the Chamois, as the temperature rose. The Arctic Willows, the Larch, and Arolla pine, for instance, are Siberian species, and do not occur in Germany.

Here and there also in the drift and the peat-mosses of the lowlands remains have been found of Alpine and Arctic species — the Arolla pine, dwarf birch (Betula nana), Arctic willows (Salix polaris, Salix retusa, and Salix reticulata), Dryas, Polygonum viviparum, etc.

Moreover, we find living colonies of high Alpine species, the seeds of which can scarcely have been carried by wind, on elevated summits in the lower districts, and in the marshes behind ancient moraines. They cannot have been brought by water, because they occur in some districts not watered by Alpine streams. On the Uetliberg Prof. Heer found two plants which especially characterise moraines—the Alpine toad flax, and a willow-herb (Epilobium Fleischeri). An Alpine fern (Asplenium septentrionale) which is said to be found nowhere else in the Canton of Zürich, occurs on the Ploughstone of Erlenbach. There are two Swiss species of Rhododendron—one with the under surface of the leaves rusty (R. ferrugineum), the other with fringed leaves (R. hirsutum). This latter species prefers a limestone soil and lower regions, so that we should expect to find it prevalent on the Jura. Yet the rusty-leaved species alone occurs there, having probably been brought by the ancient glacier from the Crystalline mountains of the Simplon and St. Bernard, where it is very abundant.[1]

The animal kingdom also affords us similar evidence. We find living colonies of Alpine and Arctic animals, especially Insects and Molluscs, on the summits of isolated mountains and in the marshes behind moraines, in association with Alpine plants and erratic blocks. Moreover, just as land animals have retired up the mountains, so have aquatic species been driven into deeper and colder waters—Nephrops norvegicus, for instance, into the depths of the sea at Quarnero, several Arctic animals into the deep waters of the Swiss lakes Wenern and Wettern. In the glacial deposits remains of various Arctic species have been met with. In the gravel-beds near Maidenhead, Charles Kingsley and I found a skull of the Musk Sheep, and remains of the same species, though rare, have since been met with in other parts of Europe. With the Musk Sheep, the Urus, the Aurochs, the Wild Horse, the Mammoth, Hairy

[1] Heer, *Primæval World of Switzerland*, vol. ii.

Rhinoceros, Reindeer, Elk, the Giant Stag or Irish Elk, Glutton, Ibex, Chamois, Cave Hyæna, Cave Bear, Polar Fox, Lemming, Ptarmigan, Marmot, Snowy Owl, etc., have been also found in glacial deposits, though fossil remains are rare in the Swiss deposits of this age.

It would be out of place in the present volume to enter into the consideration of the causes which probably led to the existence of the glacial period, or to its probable date. I have in another work (*Prehistoric Times*) discussed this question, and see no sufficient reason to change the opinion (though doubts have recently been thrown on it by Sir H. Howorth and others), that it was mainly due to astronomical causes, and reached its maximum from 50 to 100,000 years ago.

If this explanation be correct it follows that periods of cold and warmth must have followed one another more than once, at intervals of 21,000 years. And in accordance with this we find, as Morlot long ago pointed out, that the glaciers have advanced and retreated more than once.

Beds indicating warmer conditions are interposed between glacial deposits, and the Swiss and South German geologists believe that there were three periods of cold with milder intervals. In Scotland James Geikie and others have brought forward evidence of more numerous oscillations.[1]

Morlot was primarily led to this conclusion by his observations in the valley of the Dranse, south of Thonon on the Lake of Geneva, which I had the pleasure of visiting under his guidance. In this gorge between two well-marked glacial deposits is a deposit indicating a milder climate.

Again, at several places in the Canton of Zürich are beds of lignite, sufficiently thick to have been worked for fuel. They are intercalated between glacial deposits; they indicate a luxuriant vegetation and consequently a mild climate; they contain, moreover, remains of animals, such as the Hippopotamus, which could not support great cold. This can only be accounted for, I think, by assuming that these groups of animals occupied the country alternately.

Moraines which have been long exposed to the atmosphere become gradually modified at the surface. The pebbles are much weathered and sometimes quite disintegrated, even those of Granite crumbling into a sort of clay while retaining their original form. The layer affected may have a thickness of one to two feet or even more. This weathered crust often assumes a reddish color, whence it is called by Italian geologists "Ferretto."

[1] *The Great Ice Age.*

Where an old moraine has after a long interval been covered by a later one, the Ferretto enables us to distinguish between the two. It is in fact a strong confirmation of the existence of inter-glacial periods, during which the glaciers retreated, and a more genial climate prevailed. At Ivrea, for instance, the presence of Ferretto shows that the gigantic moraine known as the Serra was not formed during one long continuous glaciation. The moraines which are coated with Ferretto occupy as a rule the outer side of the morainic amphitheatre, and are covered on their inner edges by the later and inner moraines. Lignite beds also occur on the south of the Alps.[1] One of the places where an inter-glacial period is most clearly shown is in the valley of the Inn. At Hottingen, close to Innsbruck, is a great fluvio-glacial deposit, reposing on a ground moraine at a height of 1300 metres above the bottom of the valley, and capped to a height of 1900 metres by another. In these fluvio-glacial beds forty-one species of plants have been found and studied by M. Wettstein. Of these twenty-nine now live in the immediate neighbourhood, six in the Tyrol, but at a lower level, six further south, and four have not been determined.

[1] Rütimeyer, *Uber Pliocene und Eisperiode auf beiden Seiten der Alpen.*

Here then we have evidence that the valley of the Inn was (firstly) filled by a glacier to the height of 1300 metres, (secondly) that then followed a period with a climate somewhat milder than the present, succeeded (thirdly) by another glacial period, during which the valley was again filled by ice to a depth of 1900 metres.[1]

The first Swiss Ice Age is represented by ground moraine, and by "Deckenschotter"; a diluvial gravel, curiously characterised by the presence of rounded hollows. These were formerly occupied by pebbles, which have been dissolved and washed away through the hard but permeable matrix.

As this was the period of greatest glaciation, and with the exception of one or two heights, as for instance the Napf, there is, on the whole of the Central Plain between the Jura and the Rhine, no considerable area where traces of former glacial action are not to be met with. They attain in places a great thickness, sometimes even more than 400 metres.

It seems at first therefore remarkable that no terminal moraines are known which can be referred to this period. But it must be remembered that the whole country was covered by ice, with the exception of the very highest parts. Hence no doubt, as is the case in Greenland now, the surface of the ice was

[1] Penck, *Vergletscherung der Deutschen Alpen.*

very free from debris, and hence, perhaps, the peripheral glacial deposits are only represented by ground moraine.

The second Ice Age is represented by the moraines high up on the hills overlooking the valleys; and the third by moraines which form more or less complete ridges curving across the valleys, and along the slopes. It is possible that the glaciers may in some cases have been pushed forwards again over the inner moraines. At Hallwyl, for instance, the moraine immediately encircling the lake is very flat, which Dr. Mühlberg thinks may be thus accounted for.

Limits of the Ancient Glaciers

The evidence seems then conclusive that the glaciers were once far larger than at present, and the facts already summarised give some indication of the extent. Beginning with the Rhone Glacier, the former upper limit of the ice at Oberwald was 2766 metres, or 1400 above the river;[1] at Viesch it was 2700, or 1700 above the river; at Leuk 2100, or 1470 above the river; at Martigny 2080, or 1620; at Geneva 1300, or 950 metres above the Lake.[2] On the slopes of the Jura it rises highest at Chasseron, north-west of Neuchâtel,

[1] Falsan and Chantre, *Anc. Glaciers du V. du Rhone*, vol. ii.
[2] Favre, *Description Geol. du Canton de Genève*, vol. i.

opposite the valley of the Rhone, where it attains an elevation of over 1350 metres, or 977 above the lake, descending gradually to the plain on one side at Soleure, on the other at Gex. At Neuchâtel, the erratic blocks form a band about 800 feet above the lake. Above and below that line they rapidly diminish in number.

The Rhone glacier then, at the period of its greatest extension,[1] not only occupied the whole Valais and the Lake of Geneva, but rising on the Jura to a height of 1350 metres, crossed the Vuache, descended into the present Rhone valley, sweeping round by Bourg, Trévoux, Lyons, and Vienne on one side, sent a wing beyond Pontarlier as far as Salins and Ornans, and extended down the valley of the Aar as far as Waldshut, almost meeting the western extremity of the glacier of the Rhine.

The ancient glacier of the Rhine occupied the Lake of Walen, the whole valley of the Thur as far as Schaffhausen, the Klettgau, and almost to Waldshut, filled up the Lake of Constance, extending considerably to the north down the Danube as far as Sigmaringen, and for some distance its northern end follows the present watershed between the regions of the Rhine and the Danube.

Thus the two great glaciers of the Rhone

[1] See Favre, *Carte des Anciens Glaciers de la Suisse.*

and the Rhine almost enclosed those of the Aar, the Reuss, and the Limmat. That of the Aar extended as far as Berne, where there is a very fine moraine.

The glacier of the Reuss extended to Aarau, and down the Valley of the Aar to Coblenz. On the east it filled the Lakes of Egeri and Zug, extended along the Albis to the Uetliberg, and to Schlieren on the Limmat, following the valley down to Coblenz.

The glacier of the Limmat was bounded on the west by that of the Reuss; on the east from Wesen on the Lake of Walen, to the Rhine at Eglisau, following the valley to Coblenz, where therefore these four great glaciers met.

The glaciers of the Mont Blanc range not only filled the Valley of Chamouni and the country to the west as far as, and beyond, the Lake of Bourget, but flowed over to the east and joined that of the Rhone.

In fact a sea of ice covered the whole country, with the exception of some mountain tops, from Lyons to Basle, along the Rhine and the Lake of Constance across Bavaria, extending to Munich, and beyond Salzburg.

The extension of the glaciers does not however necessarily imply any very extreme climate.

Paradoxical as it may appear, glaciers require heat as well as cold: heat to create the vapour, which again condenses as snow. A succession of damp summers would do more to enlarge the glaciers than a series of cold seasons. Leblanc[1] estimated that the glacial period need not have had an average temperature of more than 7 degrees centigrade below the present, and other great authorities consider that at any rate a fall of even 5° would suffice.

The temperature decreases 1° for about every 188 metres. A fall of 5° would = 940 metres. The present snow-line being 2700 metres, would descend to 1760 metres, and the lower limit of the glaciers from 1200 metres to 360 or somewhat below Geneva, the level of which is 375. It would indeed be even lower, because the greater the snow-field, the further the glacier descends.

We have no evidence of the existence of Man in pre-glacial times, and whether he inhabited Switzerland during the inter-glacial period is still uncertain. Rütimeyer has described certain pieces of wood belonging to that period, which have been cut by some sharp instrument, and which are so arranged as to form a sort of basket-work. They certainly appear to be due to human workmanship, but the evidence is not altogether conclusive.

It has happened no doubt to many of us

[1] *Bull. Soc. Geol. France, 1843.*

to stand on some mountain-top when the surrounding summits have been covered with snow, and the intervening valleys have been filled with a thick white mist, which, especially in the early morning light, can hardly be distinguished from snow. In such a case, we have before us a scene closely resembling that which the country must have presented while it was enveloped by the ice of the glacial period.

The geologists of Bavaria have brought forward strong evidence for the belief that in Bavaria and Swabia there were three periods of great extension of the glaciers with intervals of a milder climate; and Dr. Du Pasquier, who has especially studied the fluvio-glacial deposits of Switzerland, considers that they confirm this view.

The first cold period is, he considers, represented by the so-called "Deckenschotter," of which perhaps the best known example is that on the summit of the Uetliberg near Zürich, at a height of 400 metres above the lake. It is a coarse gravel, more or less cemented together, and in which many of the pebbles have perished and disappeared, leaving rounded cavities.[1] This deposit originally formed a more or less continuous sheet, from 30 to 50 metres in thickness, deposited by the water flowing from the melting glaciers, but

[1] This structure does not occur in the true Nagelflue.

has been to a great extent removed, fragments only remaining here and there on the high ground. It is remarkable that it contains no traces of Julier or Puntaiglas Granite,[1] probably because these rocks were still covered by the Crystalline schists. The lateral Moraines of this period are unknown, but the ground Moraines are sometimes well developed. Under the Deckenschotter on the Uetliberg they attain a thickness of 2 to 20 metres. They were probably for the most part destroyed by the greater subsequent extension of the glaciers during the Second Ice Age.

The Second Ice Age is regarded as having been the most intense: it is represented by gravel-beds, still far above the present valleys, though at a lower level, and by outer and upper moraines, as for instance in the Zürich district those of Höngg, of the Albis, etc. The terminal moraines of this period were however probably beyond the boundaries of Switzerland. The Third Ice Age is indicated by the lower terraces and the moraines in the valleys. In that of Zürich, the Moraine of Killwangen was probably the outer one, while those of Zürich and Rapperschwyl represented long periods of arrest and standstill of the glaciers during their general retreat.

In theory this explanation is clear and simple, but it is not always easy to identify

[1] Du Pasquier, *Beitr. z. Geol. K. d. Schw.*, L. xxxi.

the beds. The "Deckenschotter," or upper and older bed, can indeed be generally recognised by the numerous cavities, the "rotten" condition of many of the pebbles, by its being much more frequently cemented together, and in some districts by the nature of the pebbles; in the Zürich Valley, for instance, by the absence or great scarcity of Sernifite and of the Alpine siliceous rocks, and by the frequency of Hochgebirgskalk, which does not occur in the Miocene Nagelflue[1]; but there are many glacial deposits the exact age of which is very uncertain.

The following table gives the periods, the deposits, and the great characteristic Mammalia, according to Dr. Du Pasquier[2]:—

[1] Appeli, *Beitr. z. Geol. K. d. Schw.*, L. xxxiv.
[2] *Beitr. z. Geol. K. d. Schw.*, L. xxxi.

[TABLE

TABLE OF FLUVIO-GLACIAL DEPOSITS.

Climatic Conditions.	Geological Period.	Deposits.	Organic Remains.	Corresponding Deposits in England.
Last Glacial Period.	Upper Pleistocene.	Inner Moraines. Lower Terrace grands.	Mammoth (Elephas primigenius). Rhinoceros tichorhinus.	River Gravels.
Short Inter-glacial Period.	Middle Pleistocene.	Loess Beds of Coal.	Elephas antiquus. Rhinoceros Merckii. Hippopotamus major.	...
Middle Glacial Period.	...	Outer Moraines. High Terrace gravels.	...	...
Long Inter-glacial Period.	Lower Pleistocene.	...	Elephas meridionalis.	Forest Bed.
First Glacial Period.	Upper Pliocene.	"Deckenschotter."	Elephas meridionalis. Mastodon arvernensis.	Norwich Crag.

The Glacial periods were in general, in Dr. Du Pasquier's opinion, so far as the central Swiss valleys were concerned, periods of deposit, the inter-glacial, periods of excavation.

CHAPTER VI

VALLEYS

VALLEYS and rivers are so closely associated with one another, that we generally think of them as inseparably connected; and indeed there are but few valleys which have not been deepened and profoundly modified by the action of water.

Nevertheless many valleys are "tectonic," that is to say, they are due, or stand in a definite relation, to geological structure; and there are some details of valley modelling, which are independent of water action, and which it may be convenient to consider separately.

As already mentioned the plain of Lombardy is a valley of subsidence, the lower limb, as it were, of the great arch of the Alps. It has not been excavated by the Po; on the contrary, that river has been for ages occupied in filling it up, and at Milan a boring was sunk 162 metres without reaching the bottom of the river deposits.[1]

[1] Penck, *Morphologie der Erde*, vol. ii.

The valley of the Rhine below Basle is also a line of subsidence, and the two Crystalline regions of the Black Forest and the Vosges were once continuous.

Valleys belong to several different classes, and in Switzerland have received special names, such as Vals, Combes, Cluses (Clausa, closed), Ruz, Cirques, etc., which, however, do not cover all the different kinds, and are not always used in the same sense.

In many cases valleys follow the "strike" or direction of the strata, in which case they are termed, as first suggested by De Saussure, longitudinal valleys; while in others they cut across the strata and are known as transverse or cross valleys, or cluses.

Longitudinal valleys again, as Escher von der Linth first pointed out, are of three distinct kinds.

Synclinal valleys (see *ante*, p. 44) occupy the depressions of folded strata. Many of the Jura valleys belong to this class. They are generally broad.

Anticlinal valleys are those which arise when the arch between two synclinals is broken, and the action of water being thus facilitated, a valley is formed, as for instance that of Tinière (see p. 312), which opens on the Lake of Geneva at Villeneuve.

In both these classes the strata are the same on the two sides of the valley. A third class of longitudinal valleys is due to the outcrop of layers of different hardness.

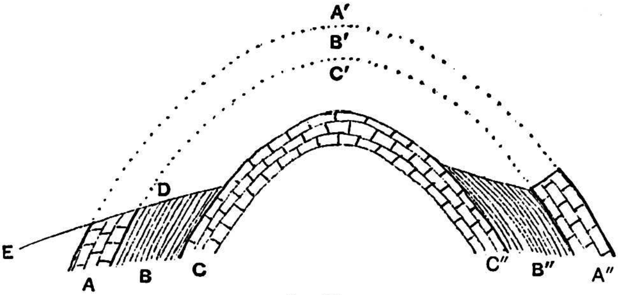


FIG. 38.

In such cases the strata on the two sides are dissimilar; such valleys are known in Switzerland as "Combes."[1]

Suppose a fractured anticlinal (*AA′A″*, Fig. 38) has been lowered by denudation to *AC′A″*, and is drained by a stream running from *C′* to *E*. If the strata are of different degrees of hardness, a soft stratum *BB′B″* between two harder ones *A* and *C* will here and there be brought to the surface.

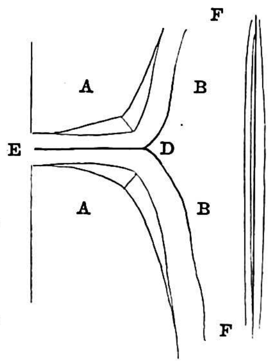


FIG. 39.

In such a case, owing to the greater softness

[1] In this country the word "Combe" is often used as synonymous with "cirque."

of the stratum *B*, secondary streams will often cut their way back as in Fig. 39, *FF*, thus forming longitudinal valleys parallel to the ridge, the sides being formed by the harder strata *A C*. Such valleys (Fig. 40) are common in the Jura.

Sometimes there may be two or even three such "Combes" along a main valley, as for instance (Fig. 41) between Mont Tendre and the valley of the Orbe, where we have four ridges of harder strata, Urgonian, Neocomian, Valangian, and finally Portland rock enclosing three combes due to the existence of softer layers.

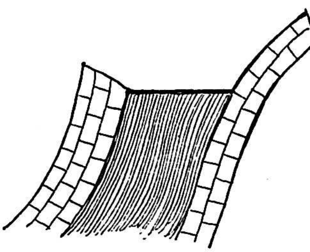


FIG. 40.

It is obvious that in this case the transverse valley *DE* (Fig. 39) is older than the longitudinal valley *FF*.

A glance at any geological map of Switzerland will show that many rivers run along the boundary, that is at the outcrop, of strata.

On the other hand, the long lines of escarpment which stretch for miles across country, and were long supposed to be ancient coast lines, are now ascertained, mainly by the researches of Whitaker, to be due to the differential action of subaerial causes. The Chalk escarpments in our own country and the great wall of the Bernese Oberland are of this character. That the longitudinal valleys owe their origin to the same cause as the mountain chains, may safely be inferred from the fact that they follow the same direction. They are in fact negative mountain chains.

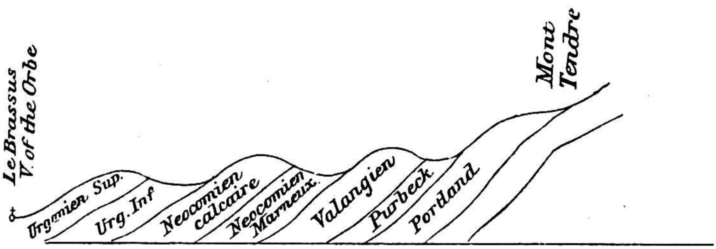


FIG. 41.—Section from the Valley of the Orbe to Mount Tendre.

TRANSVERSE VALLEYS

Transverse valleys cross the strata more or less at right angles. They are generally narrow, and often form deep gorges, more or less encumbered by fallen rock, and the harder the rock the narrower the valley.

Their character is greatly influenced by the nature of the strata, their inclination, and whether the fall coincides with, or is in opposition to, that of the beds.

Unless, however, the fall of the ground coincides exactly with that of the strata, a river running along a transverse valley will generally cross here and there harder layers which give rise to cataracts or waterfalls.

When the strata are horizontal the action of running water is comparatively slow. Steeply inclined or vertical strata on the other hand greatly facilitate erosion. Not only does the force of gravity take part in the labour, but the water sinks in more easily, and both chemical and mechanical disintegration is thus much increased.

Hence it is that while cross valleys often drain longitudinal valleys, the reverse seldom happens. Cross valleys in fact dominate longitudinal valleys.

Another respect in which, so far as Switzerland is concerned, the longitudinal differ from the transverse valleys, is that the former run approximately east to west, the latter north to south. This makes a great difference in their general aspect. In the transverse valleys not only do the two sides consist of similar rocks, but both receive approximately the same amount of light and sunshine, so that the vegetation grows under more or less similar conditions.

In the longitudinal valleys, on the contrary, not only are the strata often different on the two sides, but the northern side, which looks to the south, receives more sun, while the southern side is more in shadow. The contrast is strongly shown in the Valais itself, where the south side is green and well wooded, the north, on the contrary, comparatively dry and bare.

In some places, for instance in the valley of the Rhone below Visp, the green lines of vegetation which follow the "Bisses" or artificial water-courses are very conspicuous.

On the Lake of Zürich, though the vegetation is the same on both sides—woods and meadows and vineyards—the distribution is quite different. Both sides of the Lake are terraced, so that we have flat zones and steep slopes. On the north-east side the slopes get more sun, and hence the vines are planted on them, while the meadows and woods are on the terraces. On the west, however, the terraces get more sun, and consequently the vines are on the terraces and the meadows and woods on the slopes.

There is another class of valleys, namely, those which are due to lines of fracture or dislocation, and which may be termed fault-valleys. They are, however, comparatively rare.

One and the same river may be of a very different character in different parts of its course. It may run at one place in a longitudinal, at another in a transverse valley. The Rhone for instance occupies a transverse valley from the glacier nearly to Oberwald, a longitudinal valley from Oberwald to Martigny, and a cross valley from Martigny to the lake.

If we look at an ordinary map of Switzerland, we can at first sight trace but little connection between the river courses and the mountain chains. If, however, the map is coloured geologically, we see at once that the strata run approximately from S.W. to N.E. and that the rivers fall into two groups running either in the same line or in one at right angles to it.

The central mountains are mainly composed of Gneiss, Granite, and Crystalline Schists; the line of junction between these rocks and the Secondary and Tertiary strata on the north, runs, speaking roughly, from Hyères to Grenoble, and then by Albertville, Sion, Chur, Innsbruck, Radstadt, and Hieflau, towards Vienna. This line is followed (in some parts of their course) by the Isère, the Rhone, the Reuss, the Rhine, the Inn, and the Enns. One of the great folds shortly described in the preceding chapter runs up the Isère, along the Chamouni Valley, up the Rhone, through the Urseren Thal, down the Rhine Valley to Chur, along the Inn nearly to Kufstein, and for some distance along the Enns. Thus, then, five great rivers have taken advantage of this main fold, each of them

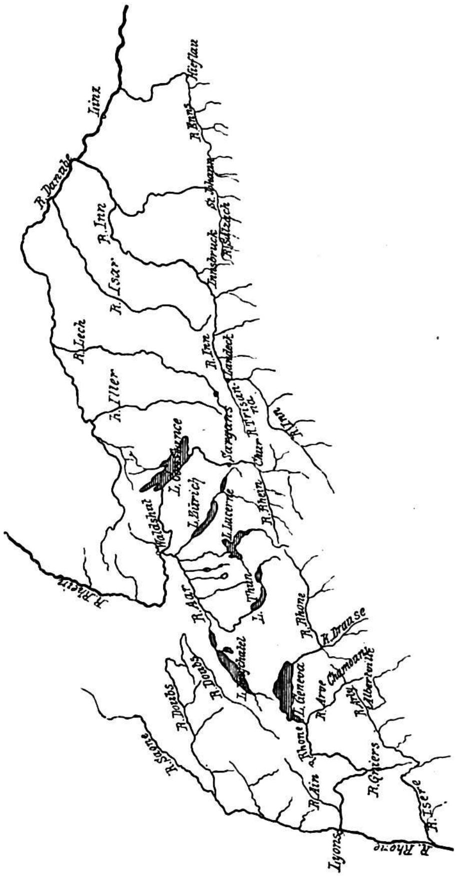


FIG. 42.—Sketch Map of the Swiss Rivers.

eventually breaking through into a transverse valley. The origin of the valley is therefore not due to the rivers running through it.

The Pusterthal in the Tyrol offers us an interesting case of what is obviously a single valley, slightly raised, however, in the centre, near Toblach, so that from this point the water flows in opposite directions —the Drau eastward, and the Rienz westward. In this case the elevation is single and slight: in the main valley of Switzerland there are several watersheds, and they are much loftier, still we may, I think, regard that of the Arve (see Fig. 42) from Les Houches to the Col de Balme, of the Rhone from Martigny to its source, of the Urseren Thal, of the Vorder Rhine from its source to Chur, of the Inn from Landeck to below Innsbruck, even perhaps of the Enns from Radstadt to Hieflau as in one sense a single valley, due to one of these longitudinal folds, but interrupted by bosses of Gneiss and Granite—one culminating in Mont Blanc, and another in the St. Gotthard—which have separated the waters of the Isère, the Rhone, the Vorder Rhine, the Inn, and the Enns. That the Valley of Chamouni, the Valais, the Urseren Thal and the Vorder Rhine really form part of one great fold is further shown by the presence of a belt of Jurassic strata nipped in, as it were, between the Crystalline rocks.

This great valley then, though immensely deepened and widened by erosion, cannot owe its origin or direction to river action, because it is occupied in different parts by different rivers running in opposite directions. We have in fact one great valley, but several rivers. It is therefore due to one original cause; it is, to use a technical term "geotectonic," and is due to the great lateral compression from S.E. to N.W. which has thrown Switzerland into a succession of great folds.

A similar case is that of the Val Ferret. The depth is no doubt mainly due to erosion, but it follows the tract of Jurassic strata which lie at the foot of the great mountain wall of the Mont Blanc range. No one who looks at the map can for an instant doubt that it is in reality a single valley; but it falls into three parts—the eastern portion is occupied by a branch of the Dranse running to the N.E.; the centre by the Doire running S.W., and the west by another branch of the Doire running N.E., the two, meeting at the foot of the Glacier de la Brenva, fall into a transverse valley and run S.E. towards Courmayeur and Aosta. Again the great valley which has given rise to the Lakes of Neuchâtel and Bienne, and which follows the course of the Aar from Soleure to Brugg, reappears in the course of the Danube below Donaueschingen.

In some respects the courses of the rivers indicate the original configuration of the surface even better than the mountains.

Many rivers after running for some distance along the strike (see p. 41) of the strata, change their direction, not turning in a grand curve, but suddenly breaking away at right angles, as for instance the Rhone at Martigny, the Aar near Brugg, the Rhine near Chur, the Inn near Kufstein.

But why should the rivers, after running for a certain distance in the direction of the main axis, so often break away into cross valleys? The explanation usually given is that transverse streams have cut their way back, and thus tapped the valley. This is no doubt true in some cases, but cannot be accepted, I think, as a general explanation.

Prof. Bonney[1] called attention to this tendency in his second lecture on the "Growth and Sculpture of the Alps." "On considering," he says, "the general disposition of the rocks constituting the Alpine chain, we perceive that, in addition to the long curving folds which determine the general direction of the component ranges, they give indications of a cross folding. The axis of these minor undulations run from about N.N.E. to S.S.W."

He suggests three possible explanations: —(1) "That the Alps are the consequence of a series of independent movements, not

[1] *Alpine Journal*, Nov. 1888.

simultaneous, so that the chain results from the accretion laterally of an independent series of wave-like uplifts; (2) that the chain was defined in its general outline by a series of thrusts proceeding outward from the basin of the North Italian plain, and afterwards folded transversely by a new set of thrusts acting at right angles to a N.N.E. line; (3) that the transverse disturbances are the older, and that the floor on which the Secondary deposits were laid down had already been disposed in parallel folds, trending roughly in the above direction."

He adopts the third hypothesis. He considers that the transverse wrinkles were perhaps Triassic, "not improbably post-Carboniferous," and therefore far older than the main longitudinal folds. "Still," he continues, "though I incline to this view, the question is so complicated that I do not feel justified in expressing a strong opinion, and rather throw out the idea for consideration than press it for acceptance. All that I will say is that I find it impossible to explain the existing structure of the Alps by a single connected series of earth movements."

Under these circumstances I have ventured[1] to make the following suggestion. If the elevation of the Swiss mountains be due to cooling and contraction leading to subsidence

[1] *Beauties of Nature.*

as suggested in page 34, it is evident, though, so far as I am aware, this has not hitherto been pointed out, that, as already suggested, the compression and consequent folding of the strata (Fig. 43) would not be in the direction of *A B* only, but also at right angles to it, in the direction *A C*, though

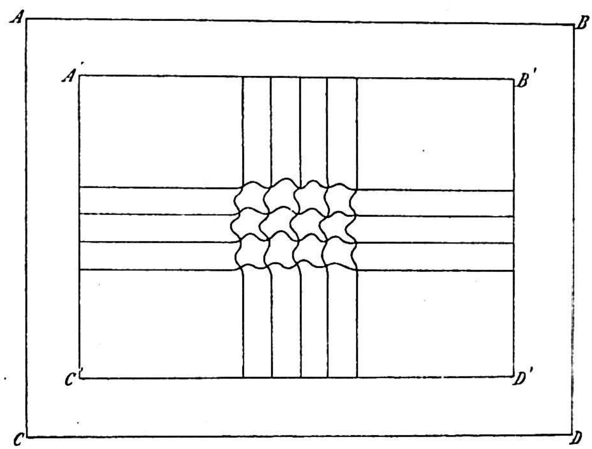


FIG. 43.—Diagram in illustration of Mountain Structure.

the amount of folding might be much greater in one direction than in the other. Thus in the case of Switzerland, as the main folds run S.W. and N.E., the subsidiary ones would be N.W. and S.E.

If these considerations are correct it follows that, though the main valleys of Switzerland have been immensely deepened and widened by rivers, their original cause was determined by tectonic causes.

Again, they indicate why the long valleys are not more continuous. If we look for instance at a map of the Jura, we see that though the ridges follow the same general curve from one end to the other, they are not continuous, but form a succession of similar, but detached ridges. Moreover even when a valley is continuous for many miles it is interrupted here and there by the cross folds.

These considerations then seem to account for the two main directions of the Swiss valleys.

I must add, however, that in Prof. Heim's opinion the cross folds occur in other parts of the Earth's surface; and such bosses as the Furca and the Ober Alp are merely the battle-grounds of different river systems, the lower levels being due to more rapid denudation.

Cirques

In some cases valleys end in a steep amphitheatre known as a "Cirque."

Cirques are characteristic of calcareous districts. They occur especially where a permeable bed rests on an impervious substratum. Under such circumstances a spring, in many cases intermittent, issues at the junction and gradually eats back into the upper stratum, forming at first a semicircular enclave, which becomes gradually elliptic, and as time passes on more and more elongated, but always with a steep terminal slope. In the Jura, cirques are numerous, and in many cases a marly bed supplies the impermeable stratum.

The Creux du Vent, and the Cirque de St. Sulpice are two of the finest examples.

Terraces

As regards the sides of valleys, other things being equal, the harder the rocks the steeper will the slope of the sides be. Very hard rocks indeed are often almost, or for some distances quite, perpendicular. The slope may be uniform in cases where the strata are similar and of great thickness, as for instance in the valley of the Reuss above Amsteg where the Bristenstock forms a grand pyramid of Crystalline rock, or where the slope coincides with the dip of the strata, as in the valley of Lauterbrunnen, where the right side of the valley presents immense sheets of Jurassic rock.

In most cases, however, some of the strata along the side of the valley are harder than others, and the consequence is that we have a succession of terraces; gentler slopes indicating the softer, and steeper ones the harder beds.

Figs. 44 and 45 show some terraces in the valley of the Bienne (Jura) due to the presence of hard calcareous layers.

These "weather" terraces must not be confused with the "river terraces" which

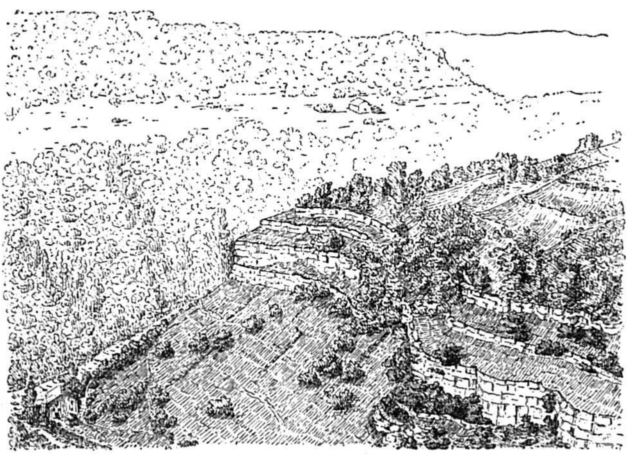


FIG. 44.—Weather Terraces in the Valley of the Bienne (Jura).

will be described in the next chapter. River terraces have no relation to the rock and follow the slope of the river, while weather terraces follow the lines of the strata.

This consideration throws light on the cases in which a river valley expands and contracts, perhaps several times in succession.

We often, as we ascend a river, after passing along a comparatively flat plain, find ourselves in a narrow defile, down which the water rushes in an impetuous torrent, but at

FIG. 45.—Section showing Weather Terraces.

the summit of which, to our surprise, we find another broad flat expanse. This is especially the case with rivers running in a transverse valley, that is to say of a valley lying at right angles to the "strike" or direction of the strata (such, for instance, as the Reuss), the water acts more effectively than in cross rocks which in many cases differ in hardness,

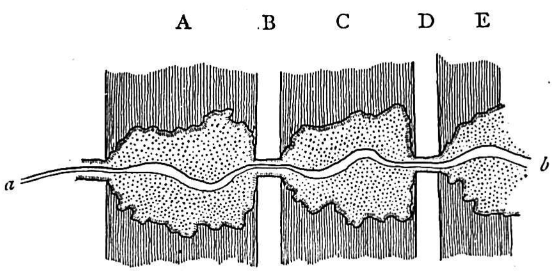


Fig. 46.—Diagram showing the course of a river through hard and soft strata.

and which therefore of course cut down the softer strata more rapidly than the harder ones; each ridge of harder rock will therefore form a dam and give rise to a rapid or cataract. In cases such as these each section of the river has for a time a "regimen" of its own.

Suppose for instance a river *a b* (Fig. 46) running across the strike of several layers differing in hardness, *A*, *C*, *E*, being soft while *B*, *D* are tough or hard. In such a case the valley will widen out at *A*, *C*, *E*. Speaking generally we may say that the depth of the valley is mainly due to the river erosion, the width to weathering. Thus the Urseren Thal on the St. Gotthard, the broad stretches of valley at Liddes, and at Chable on the Dranse (Valais), are due to the more readily disintegrated Carboniferous or Jurassic strata. On the other hand, the depth of the valley will tend to arrive at the regular "regimen" (Fig. 47), and must in any case follow its normal course; but the width will depend on the destructibility of the strata. Even however the hardest rocks will give way in time, so that the inclination of the sides will depend on the hardness of the rocks and the age of the valley. Other things being equal, the older the valley the gentler will be the slopes of the sides.

Flat valley plains may be formed either by rivers or in a lake, and the surface view is the same in either case. The inner structure, however, as shown in a section, is very different. A river plain shows irregular, lenticular masses of gravel and sand. A stream running into a lake deposits fine mud in gently inclined layers, but as soon as it comes to the water's edge the coarser gravel rolls downwards forming a steeper slope.

The great Swiss valleys are of immense antiquity; the main ones indeed were coeval with the mountains, and date back to the formation of the Alps themselves. Many indeed were even deeper in glacial times, having been to a great extent filled up by glacial deposits. Penck states that longitudinal are generally older than cross valleys. It seems to me, on the contrary, that they would as a rule have begun simultaneously. No doubt, however, there were many exceptions. The Dranse was probably an older river than the Upper Rhone. The Rhine below Basle runs in a comparatively recent depression. The greater number of the upper Swiss valleys must however date back to Miocene and some even to Eocene times, when rapid rivers were bringing down immense quantities of gravel from the slopes of the slowly rising Alps.

CHAPTER VII

ACTION OF RIVERS

ALTHOUGH the elevation of the Swiss Alps is the result of geological causes, the present configuration of the surface is mainly due to erosion and denudation. It is indeed impossible to understand the physical geography of any country without some knowledge of the action of water, and especially of rivers.

The velocity of a stream depends partly on the inclination of its bed, and partly on the volume of water; if then we study an ancient river which has passed the stormy

FIG. 47.—Final Slope of a River.

period of childhood, and forced its way through the obstacles of middle life, so that its waters run with approximately equal rapidity, we shall find that the slope diminishes from its source to the sea or lake into which it falls, with some such curve as in Fig. 47.

Such a river is said to have attained its "regimen," and this is the goal to which all rivers are striving to arrive.

The course of a river may be divided into three stages, which may be, and often are, repeated several times, viz.:—

1. Deepening and widening (the torrent).
2. Widening and levelling (the river proper).
3. Filling up (the delta).

and every part of a river in the second stage has passed through the first, every one in the third through the other two.

In the Valais the Upper glacier is a valley in the second stage, the ice-fall in the first; the plain from the foot of the fall to the Hotel in the second, from the Hotel to near Oberwald in the first; from Oberwald nearly to Niederwald in the second, from Niederwald to rather beyond Viesch in the first; then on to Brieg in the second, and from St. Maurice to Villeneuve in the third.

First Stage

In the first phase the river has a surplus of force. It may be called a torrent. It cuts deeper and deeper into its valley, and carries away the mud and stones to a lower level. The sides are steep, as steep indeed as the nature of the material will permit, and the valley is in the shape of a V with little, if any, flat bottom. The water moreover continually eats back into the higher ground. The character of the valley depends greatly on that of the strata, being narrower where they are hard and tough, broader on the contrary where they are soft, so that they crumble more easily into the stream under the action of the weather. Fig. 46.

In several cases indeed the Swiss rivers run through gorges of great depth, and yet very narrow, even in some places with overhanging walls. The Via Mala, which leads from the green meadows of Schams (Sexamniensis, from its six brooks) to Thusis, is about five miles in length with a depth of nearly 500 metres, and very narrow, in one place not more than 9 to 15 metres in breadth.

The gorges of the Aar, of the Gorner, of the Tamina at Pfäffers, of the Trient, have a similar character. These were formerly supposed to be fissures due to upheaval. They none of them however present a trace of fracture, marks of water action can in places be seen from the base to the summit, and there can be no doubt that they have been cut through by the rivers.

In certain cases indeed we have conclusive evidence. Some of these gorges are left at times quite dry, and it is easy then to see that the rock is continuous from side to side. The tunnels on the St. Gotthard line pass no less than six times under the Reuss, and there is no trace of a fault.

It may, I think, be said that the theory which attributed these gorges to a split in the rock is now definitely abandoned.

Of course, however, there are some cases in which the courses of streams have been determined by lines of fault and fracture.

Second Stage

The second stage commences where the inclination becomes so slight that the river can scarcely carry away the loose material brought from above, or showered down from the sides, but spreads it over the valley, in which it wanders from side to side, and which it tends continually to widen. Hence unless they are confined by artificial embankments, such rivers are continually changing their course, keeping however within the limits of the same valley. The width of the valley moreover depends on its age, as well as on the size of the river and the character of the rock.

If we imagine a river running down a regularly inclined plane in a more or less straight line, any inequality or obstruction, or the entrance of a side stream, would drive the water to one side, and when once diverted it would continue in the new direction, until the force of gravity drawing the water in a straight line downwards equalled that of the force tending to divert its course. Hence the radius of the curves will follow a regular curve law depending on the volume of water and the angle of inclination of the bed. If the fall is ten feet per mile and the soil

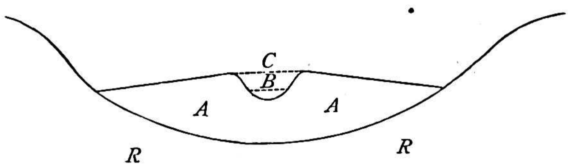


FIG. 48.—Diagrammatic Section of a Valley (exaggerated). *R R*, Rocky basis of valley; *A A*, Sedimentary strata; *B*, Ordinary level of river; *C*, Flood level.

homogeneous, the curves would be so much extended that the course would appear almost straight. Much labour has been lost in trying to prevent rivers from following their natural laws of oscillation. But rivers are very true to their own laws, and a change at any part is continued both upwards and downwards, so that a new oscillation in any place cuts its way through the whole plain of the river both above and below.

If the river has no longer a sufficient fall to enable it to carry off the materials it brings down, it gradually raises its bed (Fig. 48), hence in the lower part of their course many of the most celebrated rivers—the Po, the Nile, the Mississippi, the Thames, etc.—run upon embankments, partly of their own creation.

The Reno, the most dangerous of all the Apennine rivers, is in some places more than 9 metres above the adjoining country. Rivers under such conditions, when not interfered with by Man, sooner or later break through their banks, and, leaving their former bed, take a new course along the lowest part of their valley, which again they gradually raise above the rest.

Along the valley of the Rhone from Visp down to the Lake of Geneva there is often a marsh on one side of the valley, sometimes on both, the existence of which is to be thus explained.

This is the second stage.

Third Stage

Finally, when the stream falls into a lake or sea, or joins a main valley, it cannot carry farther the stones and mud which it has brought down, and spreads them out in the form of a fan, forming a more or less flat cone or delta—a cone if in air, a delta if under water; and the greater the volume of water, the gentler will the slope be, so that in great rivers it becomes almost imperceptible. At this part of its course, the stream instead of meandering, will tend to divide into several branches.

Cones and deltas are often spoken of as if they were identical. The surface and slope are indeed similar, but the structure of a delta formed under water (see p. 155) is by no means the same as that of a cone formed in the air.

Deltas have generally a very slight inclination, so far as the surface is concerned, while the layers below stand at a greater inclination. Most of the Swiss Lakes are being gradually filled up by the deposits of rivers. The Lake of Geneva once extended far up the Rhone Valley to St. Maurice if not to Brieg. It presents also a very typical delta at the mouth of the Dranse near Thonon. Between Vevey and Villeneuve are several such promontories, each marking the place where a stream falls into the lake.

Where lateral torrents fall into a main valley the rapidity of the current being checked, their power of transport is diminished, and similar "river cones" are formed. A side stream with its terminal cone, when seen from the opposite side of the valley presents the appearance shown in Fig. 49, or, if we are looking down the valley, as in Fig. 50, the river being often driven

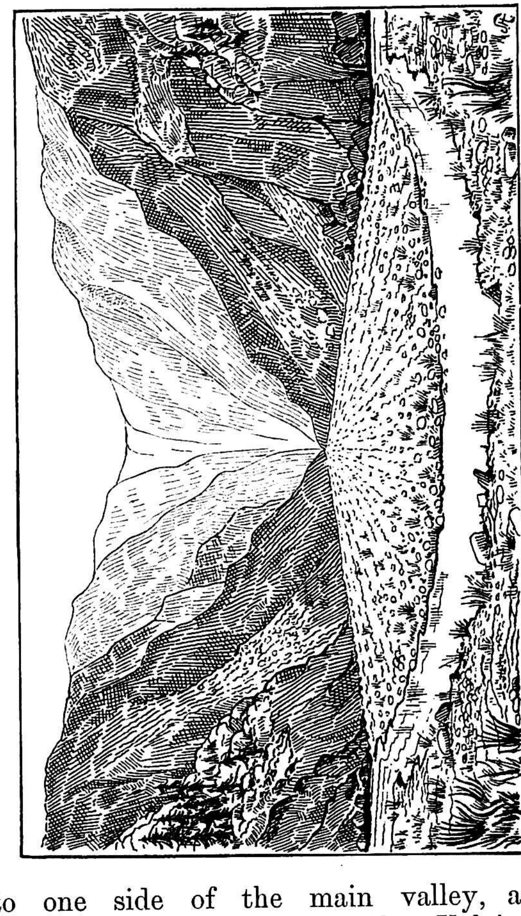


Fig. 49.—Diagram of an Alpine Valley, showing a River Cone. Front view.

to one side of the main valley, as, for instance, is the case in the Valais near

Sion, where the Rhone is (Fig. 51) driven

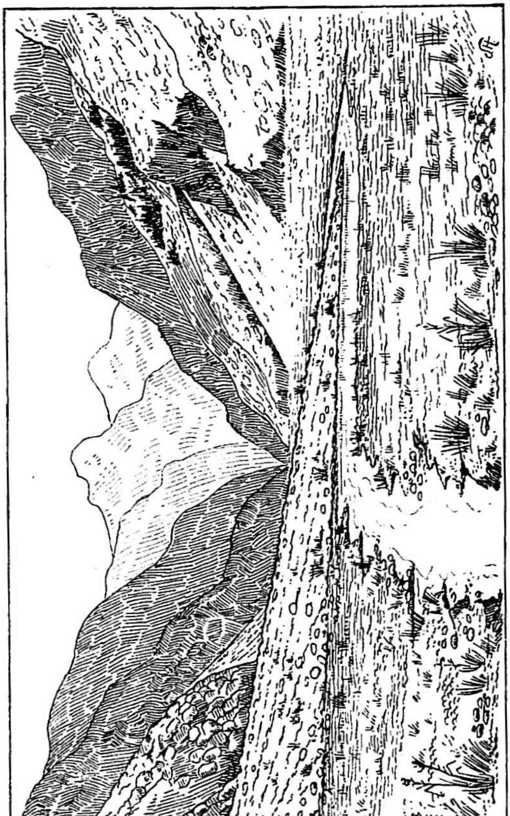


Fig. 50.—Diagram of an Alpine Valley, showing a River Cone. Lateral view.

out of its course by, and forms a curve round, the cone formed by the River Borgne.

The river cones are, in many cases, marked out by the character of the vegetation. "The Pines enjoy the stony ground particularly, and hold large meetings upon it, but the Alders are shy of it, and, when it has come to an end, form a triumphal procession all round its edge, following the convex line."[1]

The magnitude of these "river cones" then, depends on the amount and character of the materials brought into the main valley, and on the power of the river to carry them off. The felling of forests, for instance, in a lateral valley will considerably increase the erosive power of the stream, and the amount of material brought down. Rocks which yield readily to the action of weather and water will naturally supply most material, and give rise to the largest cones, especially if they form hard pebbles. On the other hand, the Flysch, which, as a rule, exercises little resistance, does not produce such important cones as might be expected, because it disintegrates into fine particles which are easily washed away. The Cargneule, on the contrary, produces large cones, because it breaks up readily, but into hard pieces.

Such cones sometimes raise the bed of the valley and dam back the water, and thus form a marshy and unhealthy tract. Thus in the Upper Valais below Oberwald is a succes-

[1] Ruskin, *Modern Painters*, vol. iv.

sion of such cones, one succeeding another, and with more or less marshy ground between them. At Münster there is a fine cone, and further down are many others at intervals. The two largest are those of the Illgraben at Leuk, and the Chamoson at the mouth of the Losentze, both of which raise the

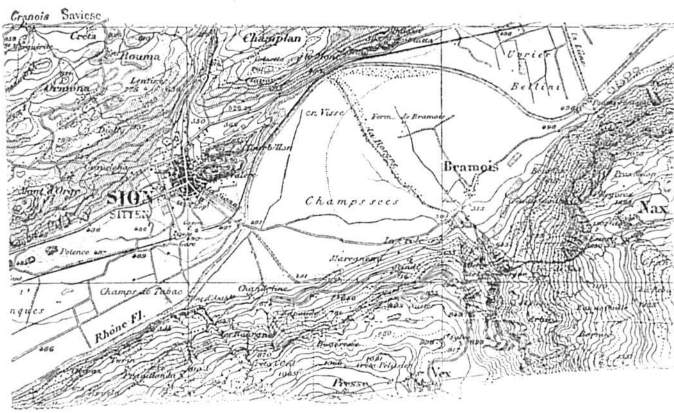


FIG. 51.—Map showing junction of Rhone and Borgne.

level of the valley above several feet. That of the Borgne (Fig. 51), near Sion, drives the river to the foot of the opposite mountain.

When at length a river has so adjusted its slope that it neither deepens its bed in the upper portion of its course, nor deposits materials, it is said to have acquired its "regimen" (Fig. 47), and in such a case the velocity will be uniform. The enlargement of the bed of a river is not, however, in proportion to the increase of its waters as it approaches the sea. Other things being equal, a river which increases in volume, increases in velocity; the "regimen" therefore would be destroyed, and the river would again commence to eat out its bed. Hence, if rivers enlarge, as for instance owing to any increase in territory, the slope diminishes.

The following figure (Fig. 52) gives a

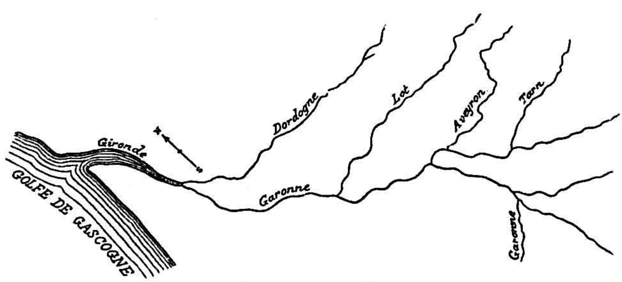


FIG. 52.—River system of the Garonne.

sketch map, and Fig. 53 represents the profiles, of the principal rivers in the valley of the Garonne, and it will be seen that the larger the river the gentler is the slope.

At present many of the smaller Swiss streams are eating into their cones and endeavouring to flatten them, owing perhaps to the gradual enlargement of the gathering-grounds.

These cones are favourite sites for villages, which are thus raised and placed out of danger of ordinary floods. The loose materials of the upper part of the cone, moreover, absorb water freely in the upper part, which is filtered, and emerges in clear springs lower down. Thus arise many of the fountains in such villages.

Now let us suppose that the force of a river is again increased, either by a fresh elevation, or locally by the removal of a barrier, or by an increase in volume owing to an addition of territory, or greater rainfall, it

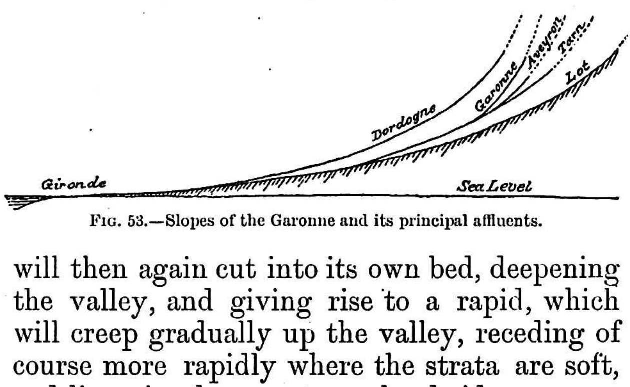


FIG. 53.—Slopes of the Garonne and its principal affluents.

will then again cut into its own bed, deepening the valley, and giving rise to a rapid, which will creep gradually up the valley, receding of course more rapidly where the strata are soft, and lingering longer at any hard ridge.

The old plain of the valley will form a more or less continuous terrace above the new course. Such old river terraces may be seen in most valleys, often indeed several, one above another.

It has been sometimes supposed that these terraces indicated greater volume of water in ancient times, sufficient indeed to fill up the whole valley to that depth. It must be remembered, however, that the terrace was formed before the lower part of the valley was excavated.

Fig. 54 is a section across the valley of the Ticino, a short distance below Airolo. It shows

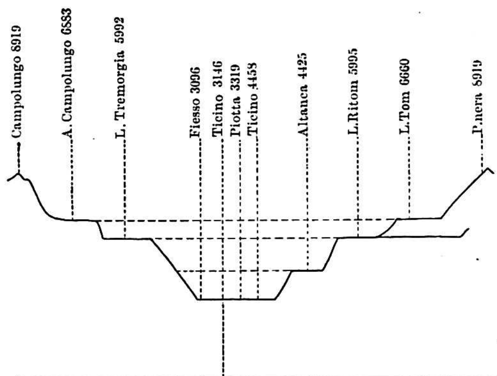


FIG. 54.—Section across the valley of the Ticino. On the left from the Ticino to Campolungo; on the right by Altanca to P.nera.

two high terraces on which the Lakes Tom and Ritom are respectively situated, and which correspond to those of Campolungo and Tremorgia on the other (W.) side of the valley. Below them is another terrace at a height of 1350 metres, on which Altanca stands. This terrace can be traced for some distance, and bears a series of villages—Altanca, Ronco, Beggio, Catto, Osco, etc. In the valley of the Ticino there is a second series of still more important towns, at or at least little above the present river bed, but in other cases, as, for instance, along the Plessur, which falls into the Rhine at Chur, the present river bed is quite narrow, and the villages are on an old river terrace high above the present water level.

Fig. 55 represents a group of terraces in the Val Camadra.

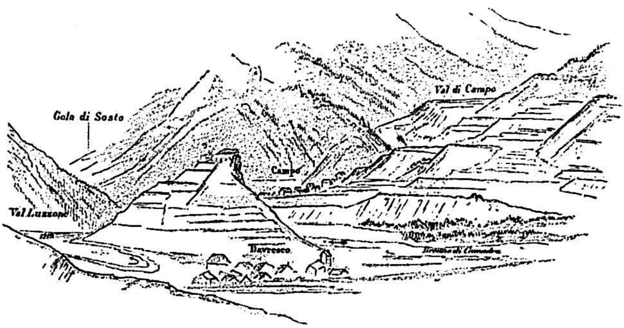


FIG. 55.—River Terraces in Val Camadra.

In each river system the terraces occupy corresponding levels, but in different systems they have no relation to one another. They afford, as we shall see in the next chapter, valuable evidence as regards the former history of rivers.

Hitherto I have assumed that the river deepens its bed vertically. This is not, however, always the case. If the strata are inclined the action of the water will tend to follow the softer stratum, as for instance, in the following diagram, where *A* represents a harder calcareous rock overlying a softer bed *B*.

The enormous amount of erosion and denudation which has taken place may be estimated from the fact that terraces can still be traced in some cases at a height of over 3000 metres.

As we approach their source, valleys become steeper and steeper. In some cases, and

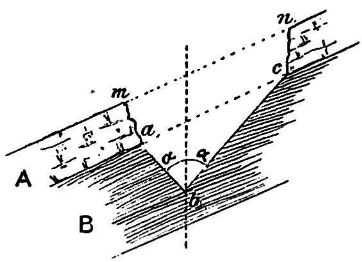


FIG. 56.—Diagram of River Valley.

especially in calcareous districts, the valleys end in a precipitous, more or less semicircular "Cirque." Springs rising at the foot of such escarpments are known as Vauclusian, from the celebrated and typical instance at Vaucluse.

Another interesting point brought out by the study of Swiss rivers, is that just as in Geology, though there have no doubt been tremendous cataclysms, still the main changes have been due to the continuous action of existing causes; so also in the case of rivers, however important the effects produced due to floods, still the configuration of river valleys is greatly due to the steady and regular flow of the water.

Floods may be divided into two classes, (1) those due to the bursting of some upper reservoir, such, for instance, as the great flood of the Dranse de Bagnes in 1818, due to the outburst of the lake, which had been dammed back by the glacier of Giétroz, or the more recent flood of St. Gervais; and (2) those due to heavy rains. No one can travel much in Switzerland without seeing the great precautions taken to confine the rivers within certain limits. In fact, what we call the river bed, is rather the low-water channel, and the whole bottom of the valley would, but for these precautions, be covered during any considerable flood. Egypt itself is the river bed of the Nile during the winter flood.

Giants' Caldrons

These are more or less circular cavities, often somewhat raised in the centre. They sometimes attain a considerable size—as much as 8 metres in diameter and 5 in depth. There is a very fine group at Lucerne, where they are known as the "Jardin du Glacier." They have been excavated in the rock by blocks of harder stone being whirled round by the action of water. Some of them no doubt, and probably those at Lucerne, were formed under glaciers, at the foot perhaps of a "moulin," but I believe that as a rule they were formed in streams.[1] Several have recently been discovered at the Maloja; there are some specimens also near Servoz in the valley of the Arve. Renevier points out that such caldrons can be seen actually in process of formation in some of the existing rivers, as, for instance, near the junction of the Rhone and the Valorsine below Geneva. These, however, will be destroyed as erosion continues. Surprise is sometimes expressed that Giants' Caldrons occur where no stream now flows. But it is just to this fact that they owe their existence. If the river had not changed its course they would long since have been destroyed.

Before closing this chapter I must say a few words about subterranean streams. These occur mainly in porous rocks, such as those of the Jura. The most considerable of these partly subterranean rivers is the Orbe, which rises originally in a little French lake, Les Rousses, traverses two others on Swiss territory, the Lake de Joux, and that of Brenet, and then disappears suddenly in the ground at the foot of a high cliff, reappearing again at a distance of 3 km. near Vallorbes.

[1] Favre, *Rech. Geol.* v. i.

Summing then up this chapter we may say that as soon as any tract of land rose out of the sea, the rain which fell on the surface would trickle downwards in a thousand rills, forming pools here and there, and gradually collecting into larger and larger streams. Whenever the slope was sufficient, the water would begin cutting into the soil and carrying it off to the sea. This action would, of course, differ in rapidity according to the slope and hardness of the ground. The character of the valley would depend greatly on the nature of the strata, being narrow where they were hard and tough; broader, on the contrary, where they were soft, so that they crumbled readily into the stream, or where they were easily split by the weather. Gradually the stream would eat into its bed until it reached a certain slope, the steepness of which would depend on the volume of water. The erosive action would then cease, but the weathering of the sides and consequent widening would continue, and the river would wander from one part of the valley to another, spreading the materials and forming a river plain. At length, as the rapidity still further diminished, it would no longer have sufficient power even to carry off the materials brought down. It would form therefore a cone or delta, and instead of wandering would tend to divide into different branches.

When we look at some great valley of denudation and the comparatively small river which flows through it, we may deem it almost impossible that so great an effect can be due to so small a cause. We can, however, find every gradation from the little gully cut out by the last summer shower up to the great Cañon of Colorado. We must consider not only the flow of the water, but the lapse of time, and remember that our river valleys are the work of ages. Moreover, even without postulating any greater rainfall in former times, we must bear in mind that we are now looking at rivers which have attained or are approaching their equilibrium; they are comparatively steady, and even aged, and we cannot measure their present effect by that which they produced when they possessed the energy and impetuosity of youth.

From this point of view the upper part of a river valley is peculiarly interesting. It is a beautiful and instructive miniature. The water forms a sort of small-meshed net of tiny runnels.

Here we can as it were surprise the river at its very commencement; we can find streamlets and valleys in every stage, a quartz pebble may divert a tiny stream, as a mountain does a great river; we find springs and torrents, river terraces and waterfalls, lakes and deltas in the space of a few square metres, and changes which on a larger scale require thousands of years pass under our eyes. And as we watch some tiny rivulet, swelling gradually into a little brook, joined by others from time to time, growing to a larger and larger torrent, to a stream, and finally to a great river, it is impossible to resist the conclusion gradually forced upon us, that, incredible as it must at first sight appear, even the greatest river valleys, though their origin may be due to the original form of the surface, owe their present configuration mainly to the action of rain and rivers.

Note.—Throughout western Europe a large proportion of the river names fall into three groups.

From the Old German Aha, Celtic Uisge, Gaelic Oich, Latin Aqua (Water), softened into the French Eau, we have the Aa, Awe, Au, Avon, Aue, Ouse, Oise, Grand Eau, Aubonne, Oich, Ock, Aach, Esk, Uisk, etc.

From the Celtic Dwr (Greek ὕδωρ), we have Oder, Adour, Thur, Dora, Douro, Doire, Durance, Dranse, Doveria, etc.

From the Celtic Rhin, or Rhedu, to run (Greek ῥέω), we have the Rhine, Rhone, Reuss, Reno, Rye, Ray, Raz, etc.

The names Aa and Drance or Dranse are so common in Switzerland that it is necessary to specify them by some further description, such as the Engelberger Aa, the Aa of Alpnach, the Milch Aa, Hallwyler Aa, Wäggithaler Aa, etc.

The Drance which falls into the Lake of Geneva near Thonon is perhaps the Drance *par excellence*, but in the same river system we have also the Drance de Bagne, the Drance d'Entremont, and the Drance de Ferret.

In the case of the Rhine also there is the Vorder Rhein, Mittel Rhein, Hinter Rhein, Oberhalbstein Rhein, Averser Rhein, Safien-Rhein, etc.

CHAPTER VIII

DIRECTIONS OF RIVERS

THE general direction of the river-courses in any country is determined in the first instance by the configuration of the surface at the time of its becoming dry land. The least inequality in the surface would determine the first direction of the streams, and thus give rise to channels, which would be gradually deepened and enlarged. They are, however, in many cases materially modified by subsequent changes of relative level, and by the results of erosion, which acts of course much more rapidly on some strata than on others. It is as difficult, however, for a river as it is for a man to get out of a groove.

If we imagine a district raised in the form of a regular dome, the rivers would radiate from the summit in all directions. The lake district in the north of England; the Plateau of Lanneme-zan in the south of France, and the Ellsworth Arch in the Henry Mountains,[1] offer us approximations to such a condition. It seldom happens, however, that the case is so simple, and the directions of rivers offer many interesting problems, which are by no means easy to solve.

As already mentioned (*ante*, p. 144), the Swiss rivers follow two main directions, at right angles to one another, namely, S.W. by N.E. and N.W. by S.E. The first follows the strike of the strata. The explanation of the second is not so simple. The probable cause, however, which has determined the two main directions of the Swiss rivers has been already suggested (*ante*, p. 150).

The principal Swiss rivers must be of great antiquity. Some of the streams in the eastern and central parts of the Alps probably commenced even in Eocene times. The Nagelflue was brought down from the mountains by rivers which probably occupied the upper parts of the valleys of the Aar, Reuss, etc.

Nevertheless there have been great changes in the courses of the Swiss rivers. These are ascribable to four main causes:—First, it must be remembered that streams are continually eating back into the hills. In many cases they cut completely through them, and if the valley into which they

[1] See Gilbert, *Geology of the Henry Mountains.*

thus force their way is at a higher level, they carry off the upper waters; Secondly, later earth movements in many cases diverted the rivers; Thirdly, they have in many cases been diverted by masses of glacial deposits; and Fourthly, the summit ridge of the Alps is slowly retreating northwards, which affects the river system of all the upper districts.

In the great Swiss plain the country slopes on the whole northwards from the Alps, so that the lowest part is that along the foot of the Jura. Hence (Fig. 42) the main drainage runs along the line from Yverdun to Neuchâtel, down the Zihl to Soleure, and then along the Aar to Waldshut. The Upper Aar, the Emmen, the Wigger, the Suhr, the Wynen, the lower Reuss, the Sihl, and the Limmat, besides several smaller streams, running approximately parallel to one another—N.N.W., and at a right angle with the main axis of elevation, all join the Aar from the south, while on the north it does not receive a single tributary of any importance.

On the south side of the Alps again, and for a corresponding reason, all the great affluents of the Po—the Dora Baltea, the Sesia, the Ticino, the Olonna, the Adda, the Adige, etc., come from the north, and all run S.S.E. from the axis of elevation to the Po.

Indeed, the general slope of Switzerland being from the ridge of the Alps towards the north, most of the large affluents of rivers running in longitudinal valleys fall in on the south, as, for instance, those of the Isère from Albertville to Grenoble, of the Rhone from its source to Martigny, of the Vorder Rhine from its source to Chur, of the Inn from Landeck to Kufstein, of the Enns from its source to near Admont, of the Danube from its source to Vienna, and, as just mentioned, of the valley from Yverdun to Waldshut. Hence also, whenever the Swiss rivers running east and west break into a transverse valley, as the larger ones all do, and some more than once, they invariably, whether originally running east or west, turn towards the north.

But why has the country this slope? Why is it lowest along the wall of the Jura? As has been already pointed out, this part of Switzerland was formerly a great valley, which was partially filled by river deposits. It is indeed a great "cone" due to many rivers which flowed down from the rising Alps. This being so, the general slope is naturally from, and the lowest part is that farthest away from, the mountains.

It must be remembered that the conformation of the strata situated below by no means always correspond with that of the surface.

Again it will sometimes happen that rivers follow a course which is very difficult to explain, because, in fact, it has no reference to the present configuration of the surface, but has been determined by the existence of strata which have now disappeared.

It often happens, for instance, that the rivers now run apparently on an anticlinal, and

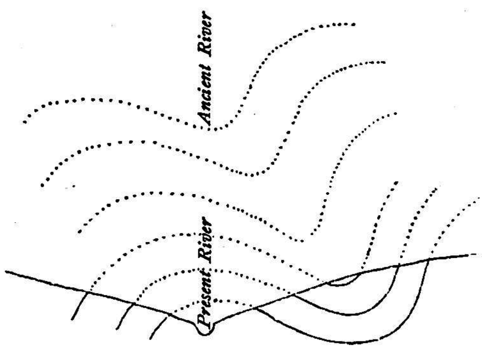


FIG. 57.—Diagram to illustrate a river now running in an anticlinal.

have a synclinal on one side (Fig. 57), as, for instance, the Rhine at Dissentis (see Fig. 135).

The folds, however, being inclined, it will be seen from the dotted lines that when the river began its labour it perhaps did run in the synclinal, but having cut its way directly downwards is now some way from it, and will diverge further and further as erosion proceeds.

It is a remarkable fact that great folds by no means always determine the watershed, but, on the contrary, rivers often cut through ranges of mountains.

Thus the Elbe cuts right across the Erz-Gebirge, the Rhine through the mountains between Bingen and Coblenz, the Potomac, the Susquehannah, and the Delaware through the Alleghanies. Even the chain of the Himalayas, though the loftiest in the world, is not a watershed, but is cut through by rivers in more than one place. The case of the Dranse will be alluded to further on. In these instances the rivers probably preceded the mountains. Indeed, as soon as the land rose above the waters, rivers would begin their work, and having done so, if a subsequent fold commenced, unless the rate of elevation exceeded the power of erosion of the river, the two would proceed simultaneously, so that in many cases the river would not alter its course, but would cut deeper and deeper as the mountain range gradually rose.

In other cases where we generally speak of a river suddenly changing its direction, it would be more correct to say that it falls into the valley of another stream. Thus the Aar, below Berne, instead of continuing in the same direction, by what seems to have been its ancient course, along the broad valley now only occupied by the little Urtenenbach, suddenly turns at a right angle, falling into the valley of the Sarine, near Oltigen.

Take again the Rhone (Fig. 58). It is said to turn at a right angle at Martigny, but in reality it falls into and adopts the transverse valley, which properly belongs to the Dranse; for the Dranse is probably an older river and ran in the present course

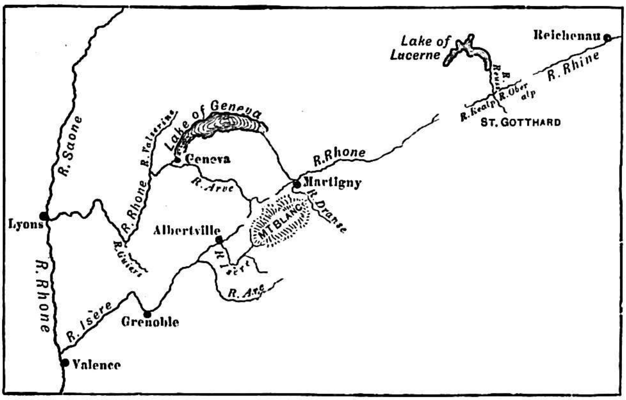


FIG. 58.—Sketch map of the Rhone and its tributaries.

even before the origin of the Valais. This would seem to indicate that the Oberland range is not so old as the Pennine, and that its elevation was so gradual that the Dranse was able to wear away a passage as the ridge gradually rose. After leaving the Lake of Geneva the Rhone follows a course curving gradually to the south, until it falls into and adopts a valley which properly belongs to the Valserine, and afterwards another belonging to the little river Guiers; it subsequently joins the Ain, and finally falls into the Saône. If these valleys were attributed to their older occupiers, we should therefore confine the name of the Rhone to the portion of its course from its source to Martigny.

From Martigny it invades successively the valleys of the Dranse, Valserine, Guiers, Ain, and Saône. In fact, the Saône receives the Ain, the Ain the Guiers, the Guiers the Valserine, the Valserine the Dranse, and the Dranse the Rhone. This is not a mere question of names, but also one of antiquity. The Saône, for instance, flowed past Lyons to the Mediterranean for ages before it was joined by the Rhone. In our nomenclature, however, the Rhone has swallowed up the others. This is the more curious from the fact that of the three great rivers which unite to form the lower Rhone, namely, the Saône, the Doubs, and the Rhone itself, the Saône brings for a large part of the year the greatest volume of water, and the Doubs has the longest course.

We will now consider some of the cases in which Swiss rivers have altered their courses. In some of these the change of direction is doubtless due to the fact that some stream at the lower level, or with a greater fall, has eaten its way back, and so tapped the higher valley.

Rivers, indeed, have their adventures and vicissitudes, their wars and invasions. Take, for instance, the Upper Rhine (Fig. 59), of which we have a very interesting account by

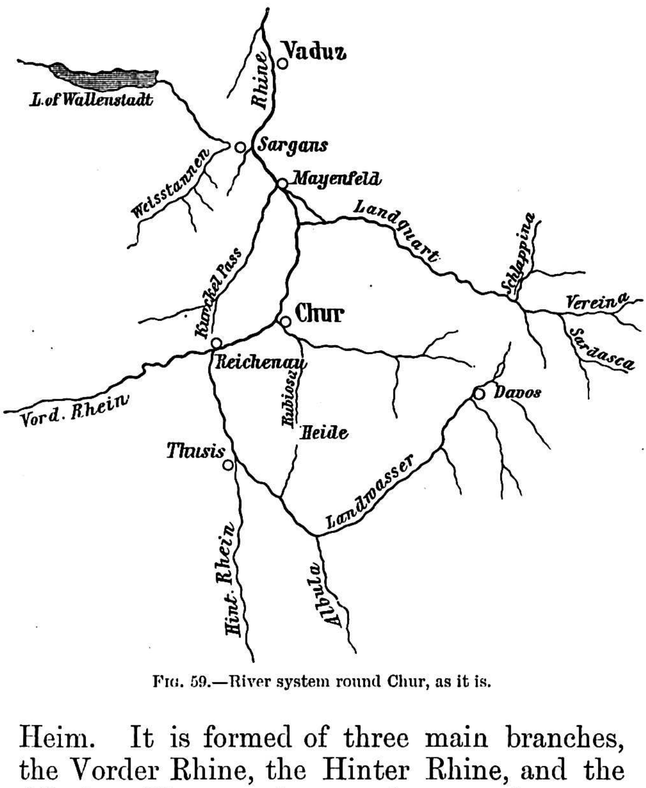


FIG. 59.—River system round Chur, as it is.

Heim. It is formed of three main branches, the Vorder Rhine, the Hinter Rhine, and the Albula. The two latter, after meeting near Thusis, unite with the Vorder Rhine at

Reichenau, and run by Chur, Mayenfeld, and Sargans into the Lake of Constance at Rheineck. At some former period, however,

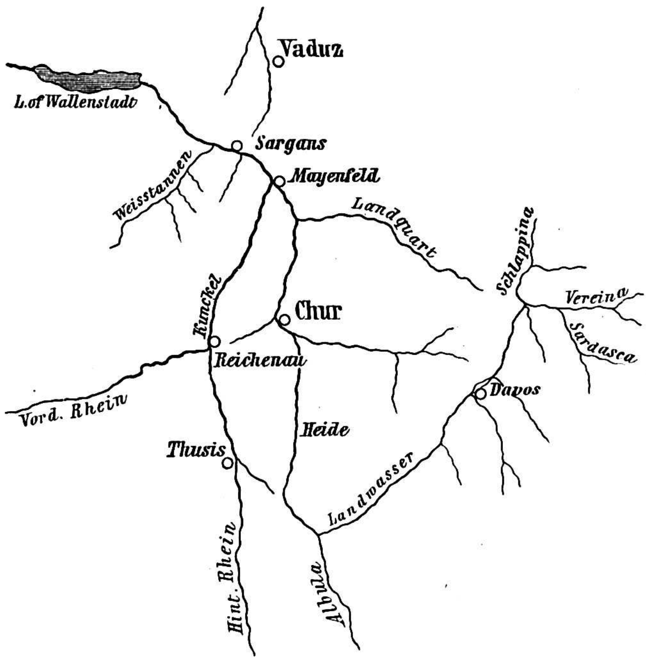


FIG. 60.—River system round Chur, as it used to be.

the drainage of this district was very different.

The Vorder and Hinter Rhine united then, as they do now, at Reichenau, but at a much higher level, and ran to Mayenfeld (Fig. 60), not by Chur, but by the Kunkels Pass to Sargans, and so onwards, not to the Lake of Constance, but to that of Zürich. The Landwasser at that time rose in the Schlappina Joch, and after receiving as tributaries the Vereina and the Sardasca, joined the Albula, as it does now at Tiefenkasten; but instead of going round to meet the Hinter Rhine near Thusis, the two together travelled parallel with, but at some distance from, the Hinter Rhine, by Heide to Chur, and so to Mayenfeld.

As we look up from Tiefenkasten towards Lenz and the Parpan Pass it seems almost incredible that the Oberhalbstein Rhine can ever have taken that course. I give therefore (Fig. 61) the following profile showing the old river terrace, but with the height exaggerated in comparison with the distance. This, however, does not affect the relative elevations. The dotted lines follow the natural slope of a river, and the strengthened parts show where portions of terrace still remain. It is obvious that before the ancient Schyn had cut its way up to Tiefenkasten the Oberhalbstein Rhine and the Landwasser flowed over the Parpan Pass, and not only flowed over it, but have cut it down some 610 metres, that is to say, when the river flowed over it with its natural regimen in relation to the valley it was at a height of 2200 metres, and has left a fragment

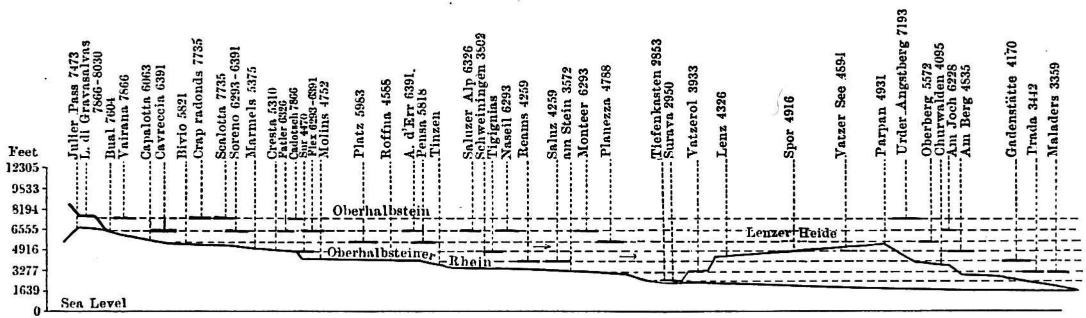


FIG. 61.—Longitudinal Profile of the Oberhalbstein Rhine and the Parpan Pass. 1=100,000.

of terrace at that height at Vor der Angstberg, the Parpan itself being only 1500 metres.

In fact, the Parpan and Kunkels passes are deserted river valleys, showing on each side river terraces, and were obviously once the beds of great rivers, very different from the comparatively small streams which now run in their lower parts.

In the meanwhile, however, the Landquart stealthily crept up the valley, attacked the ridge which then united the Casanna and the Mädrishorn, and gradually forcing the passage between Dörfli and Klosters, invaded the valleys of the Schlappina, Vereina, and Sardasca, absorbed them as tributaries, detached them from their allegiance to the Landwasser, and annexed the whole of the upper province, which had formerly belonged to that river.

The Schyn also gradually worked its way upwards from Thusis till it succeeded in sapping the Albula, and carried it down the valley to join the Vorder Rhine near Thusis. In what is now the main valley of the Rhine above Chur, another stream ate its way back, and eventually tapped the main river at Reichenau, thus diverting it from the Kunkels and carrying it round by Chur.

It is possible that in the distant future the Landwasser may be still further robbed of its territory. The waters of the Davos Lake, the

Flüela, the Dischma, and the Kuhalpthal now take a very circuitous route to Chur, and it is not impossible that they may be captured and carried off by the Plessur.

At Sargans a somewhat similar process was repeated, with the addition that the material brought down by the Weisstannen, or perhaps a rockfall, deflected the Rhine, just as we have seen (p. 167) that the Rhone was pushed on one side by the Borgne. The Rhone, however, had no choice, it was obliged to force, and has forced, its way over the cone deposited by the Borgne. The Rhine, on the contrary, had the option of running down by Vaduz to Rheinbach, and has adopted this course.

The association of the three great European rivers—the Rhine, the Rhone, and the Danube —with the past history of our race, invests them with a singular fascination, and their own story is one of much interest. They all three derive part of their upper waters from the group of mountains between the Galenstock and the Bernardine, within a space of a few miles; on the east the waters now run into the Black Sea, on the north to the German Ocean, and on the west to the Mediterranean. But it has not always been so. Their head-waters have been at one time interwoven together.

The present drainage of Western Switzerland is very remarkable. If you stand on a height overlooking the valley of the Arve near Geneva, you see a semicircle of mountains—the Jura, the Vuache, the Voirons, etc., which enclose the west end of the Lake of Geneva; the Arve runs towards the lake, which itself opens out towards Lausanne, where a tract of low land alone separates it from the Lake of Neuchâtel and the valley of the Aar. This seems the natural outlet for the waters of the Rhone and the Arve. As a matter of fact, however, they escape from the Lake of Geneva at the western end, through the remarkable defile of Fort de l'Ecluse and Maupertuis, which has a depth of nearly 300 metres, and is at one place not more than 14 feet across. There are reasons, moreover, as we shall see presently, for considering the defile to be of comparative recent origin. Moreover, at various points round the Lake of Geneva, remains of lake terraces show that the waters once stood at a level much higher than at present. One of these is rather more than 76 metres above the lake.

The low tract between Lausanne and Yverdun has a height of 76 metres (250 feet) only, and corresponds with the above-mentioned lake terrace. The River Venoge, which rises between Rolle and the Mont Tendre, runs at first towards the Lake of Neuchâtel, but near La Sarraz it divides; the valley continues in the same direction, and some of the water joins the Nozon, which runs to the Lake of Neuchâtel at Yverdun; but the main river turns sharply to the south, and falls into the Lake of Geneva to the east of Morges.

It is probable, therefore, that when the Lake of Geneva stood at the level of the 76 metres terrace the waters ran out, not as now at Geneva and by Lyons to the Mediterranean, but near Lausanne by Cissonay and Entreroches to Yverdun, and through the Lake of Neuchâtel into the Aar and the Rhine.

But this is not the whole of the curious history. At present the Aar makes a sharp turn to the west at Waldshut, where it falls into the Rhine, but there is reason to believe that at a former period, the river continued its course eastward to the Lake of Constance, by the valley of the Klettgau, as is indicated by the presence of gravel beds containing pebbles which have been brought, not by the Rhine from the Grisons, but by the Aar from the Bernese Oberland, showing that the river which occupied the valley was not the Rhine but the Aar. It would seem also that at one time the Lake of Constance stood at a considerably higher level, and that the outlet was, perhaps, from Friedrichshafen to Ulm, along what are now the valleys of the Schussen and the Ried, into the Danube.[1]

[1] Du Pasquier, *Beitr. z. Geol. K. d. Schw.*, L. xxxi.

The River Aach, though a tributary of the Rhine, still derives its head-waters from the valley of the Danube. A part of the water of the Danube sinks into fissures in the Jurassic rocks at Immendingen, and makes its appearance again as copious springs at Aach, from whence they flow into the Lake of Constance near Rudolphzell.

Thus the head-waters of the Rhone appear to have originally run between Morges and

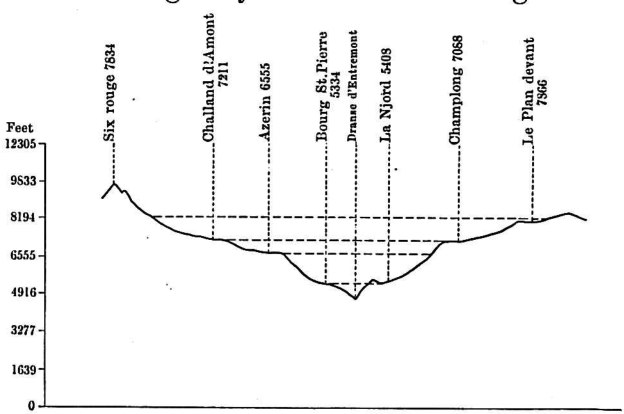


FIG. 62.—Section across the Val d'Entremont at Bourg St. Pierre. 1=100,000.

Lausanne and to the Lakes of Neuchâtel and Constance into the Danube, and so to the Black Sea. Then, after the present valley was opened between Waldshut and Basle, they flowed by Basle and the present Rhine, and after joining the Thames, over the plain which now forms the German Sea into the Arctic Ocean between Scotland and Norway. Finally, after the opening of the passage at Fort de l'Ecluse, by Geneva, Lyons, and the valley of the Saône, to the Mediterranean.

In the upper parts of the district there have also been some changes.

Fig. 62 shows the river terraces on the Dranse d'Entremont, near Bourg St. Pierre, where the Society for the protection of Alpine

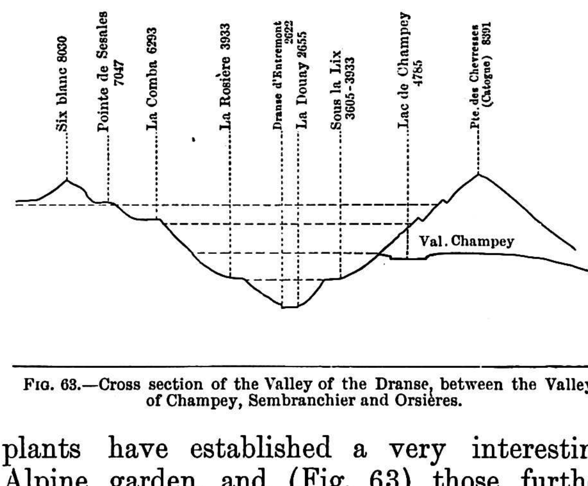


FIG. 63.—Cross section of the Valley of the Dranse, between the Valley of Champey, Sembranchier and Orsières.

plants have established a very interesting Alpine garden, and (Fig. 63) those further down the valley near La Douay.

The uppermost of these terraces is at a height of 2200 metres. The col leading to the Vallée de Champey is at a height of about 1500 metres, and until the river had reached a lower level than this, the waters of the Dranse followed what the map shows was their natural course down the Vallée de Champey. Eventually, however, the Orsières branch of the Dranse de Bagne cut its valley back and carried off the upper waters to join the Dranse de Bagne at Sembranchier. This was facilitated by the comparative softness of the Jurassic strata and Gray Schists, while the Vallée de Champey is in Protogine, Felsite, and Porphyry, which offered a much greater resistance to the action of the water.[1]

The Trient also has changed its course. Originally it ran over the Col de la Forclaz down to Martigny. In this case the change is due, not to any difference in the hardness of the rock, but to the greater fall, and consequently greater erosive power, of the Eau Noire.

It would also seem that some of the Vaud and Frieburg rivers must be older than the final elevation of the mountains at the north-east end of the Lake of Geneva. Gillieron points out that the Broye, the Mionnaz, the Flon, and I may add the Sarine, from Sarnen to below Château d'Oex, run towards the Lake of Geneva, until they are stopped by the mountains between Chatel St. Denis and the Rocher de Naye, and forced to return northwards.

[1] Bodmer, p. 21.

There is also one important change which applies to the whole crest of the Alps.

Watersheds are at first determined by the form of the earliest terrestrial surface, and if the slopes in each side are equal they will be permanent; on the other hand if, as in the Alps, one side is much steeper than the other, it will be worn back more rapidly. Hence the whole crest of the Alps is, of course very slowly, moving northwards. This is specially marked in the case of the Engadine (see ch. xxiv).

These changes and struggles have by no means come to an end. In some cases we can already foresee future changes. For instance, the Nolla, which falls into the Hinter Rhine at Thusis, is rapidly eating back into the mountains near Glas, and in, geologically speaking, a comparatively short time it will probably invade the Valley of the Versam, carry off its upper feeders, and appropriate the waters from the upper valley. So rapidly is the change progressing that after even a few hours' rain the Nolla becomes quite black. In its upper part the Bündnerschiefer is saturated with water, and reduced almost to a black mud. It may be said to be continually in slow movement down to the valley, and the houses of Glas and Tschappina have to be continually repaired. Some have moved as much as 60 metres downwards in thirty years.

Age of Rivers

It follows from these considerations not only that the Swiss rivers are of very different ages, some being of comparatively recent origin, while others date back to very great antiquity, but that different parts of what is now considered a single river are of very different ages and have a very different history.

The southern part of the Central Alps are supposed to have been first raised above the waters, and to have formed an Island in Eocene times, to which therefore some of the head-waters date back. It is, however, clear that the rivers crossing the Miocene deposits of Central Switzerland cannot have commenced until after the Miocene strata had been raised and become dry land. In fact the upper parts of the Reuss and the Aar probably represent the rivers which brought down the great masses of Miocene gravel which now form the lowlands of Switzerland, and through which they subsequently cut the lower parts of their courses, which therefore must necessarily be of much less ancient origin; even these valleys, however, were as a rule excavated to their full depth before the Glacial period, and must therefore be of immense antiquity.

CHAPTER IX

THE LAKES

THE Alps are surrounded by a beautiful circle of lakes. We have on the north, besides many smaller ones, those of Constance, Walen and Zürich, Zug, Lucerne, Brienz and Thun, Geneva; on the south the Lago Maggiore, Lugano, Como, Iseo, and Garda, which seem to radiate as it were from the great central mass of the St. Gotthard. I do not mention the Lakes of Neuchâtel or Morat, because they belong to a different category.

These great lakes are clearly not parts of a former inland sea. They stand at very different levels. The Lake of Brienz, for instance, is 190 metres above that of Geneva; that of Orta is 225 metres above the Lake of Garda.

But in considering the origin of these lakes we must have regard not merely to the surface level of the water, but also that of the bottom. When we give the level of a lake it is usual to quote that of the upper surface, but the bottom is perhaps even more important, and as we shall see from the following table, there is a great contrast between the two :—

	Surface Level.	Greatest Depth.	Bottom Level.
Constance	395 metres	252 metres	143 metres
Walen	423 ,,	151 ,,	272 ,,
Zürich	409 ,,	142 ,,	267 ,,
Zug	417 ,,	198 ,,	219 ,,
Lucerne	437 ,,	214 ,,	223 ,,
Sempach	507 ,,	87 ,,	420 ,,
Brienz	566 ,,	261 ,,	305 ,,
Thun	560 ,,	217 ,,	343 ,,
Geneva	375 ,,	309 ,,	66 ,,
Neuchâtel	432 ,,	153 ,,	279 ,,
Bienne	434 ,,	74 ,,	360 ,,
Orta	290 ,,	143 ,,	147 ,,
Maggiore	194 ,,	655 ,,	–461 ,,
Como	199 ,,	414 ,,	–215 ,,
Lugano	266 ,,	288 ,,	– 22 ,,
Varese	239 ,,	29 ,,	210 ,,
Iseo	185 ,,	346 ,,	–161 ,,
Garda	65 ,,	346 ,,	–281 ,,

These depths are the more remarkable if we compare them with certain seas. For instance, the English Channel is nowhere more than 50 metres in depth, the North Sea, 60.

The original depth of the Lakes was, moreover, even greater, because the present bottom is in every case covered by alluvium of unknown, but no doubt considerable, thickness.

The Lakes of Neuchâtel and of Bienne only differ by 1 metre as regards the water level, but the Neuchâtel basin is 60 metres deeper than that of Bienne.

The great Italian lakes, as shown in the foregoing table, descend below, sometimes much below, the sea level.

The lakes, moreover, are in some cases true rock basins. In the case of Geneva, for instance, though the actual outlet is over superficial debris the solid rock appears in the river bed at Vernier only 10 metres below the surface of the lake, or 300 metres above the deepest part.

The materials brought down by the rivers have not only raised the bottoms of the lakes, but have diminished their area by filling them up in part, especially at the upper ends. It is evident that they were at one time much larger than they are now. The Lake of Geneva extended at least to Bex and perhaps to Brieg, that of Brienz to Meiringen, of Lucerne to Erstfeld, the Walensee to Chur, the Lake of Constance at least to Feldkirch, the Lago Maggiore to Bellinzona, that of Como to Chiavenna.

Moreover, the lakes of Brienz and Thun

formed one sheet of water, as also did the Walensee and the Lake of Zürich.

Very slight changes might again greatly enlarge the lakes. For instance, if the narrow outlet of the Aar, somewhat below Brugg, were again closed, a great part of the central Swiss plain would be submerged.

The problem of the origin of lakes is by no means identical with that of rivers. We have not only to account for the general depth of the valley—this may be due to running water—but for the exceptional basin of the lake; running water produces valleys, it tends to fill up and drain lakes.

To what then are lake basins due?

It used to be supposed that many lakes were due to splits and fractures. I do not, however, know of any Swiss lake which can be so explained.

We may divide Lakes into four classes:—

1. Lakes of embankment.
2. Lakes of excavation.
3. Lakes of subsidence.
4. Crater lakes.

In many cases, however, a lake may be due partly to one of these causes and partly to another, and for convenience of description they may be dealt with under eight heads:—

1. Those due to irregular accumulations

of drift; these are generally small and quite shallow.

2. Corrie lakes.

3. Those due to moraines.

4. Those due to rockfalls, landslips, river cones, glaciers, or lava currents damming up the course of a river.

5. Loop lakes.

6. Those due to subterranean removal of soluble rock, such as salt, or gypsum. These principally occur in Triassic areas.

7. Crater lakes.

8. The great lakes.

1. As regards the first class, we find here and there on the earth's surface districts sprinkled with innumerable shallow lakes of all sizes, down to mere pools. Such, for instance, occur in the district of Le Pays de Dombes between the Rhone and the Saône, that of La Sologne near Orleans, in parts of North America, in Finland, and elsewhere. Such lakes are, as a rule, quite shallow. They are due to the fact of these regions having been covered by sheets of ice which strewed the land with irregular masses of clay, gravel, and sand, on a stratum impervious to water, either of hard rock such as granite or gneiss, or of clay, so that the rain cannot percolate through it, and where there is not sufficient inclination to throw it off.

2. Corrie lakes may be thus explained. Let us assume a slope (Fig. 64, *a b c d*) on which snow and ice (*e*) accumulates.

The rocks and fragments falling from the heights would accumulate at *d*. Moreover, the ice would tend to form a hollow at *c* (Fig. 65) where the pressure would be greatest.

If subsequently the snow and ice melted, water would accumulate in the hollow

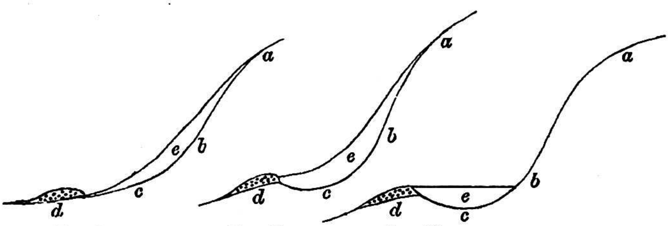


FIG. 64. FIG. 65. FIG. 66.

Diagrams to illustrate Corrie Lakes.

(Fig. 66), and lakes thus formed are common in mountainous districts, where they have a special name—Corries in Scotland, Oules in the Pyrennees, Botn in Norway, Karwannen in the German Alps, etc.

3. A third class of lakes is that due to river valleys having been dammed up by the moraines of ancient glaciers.

To this cause are due the Lake of Zürich (in part), the Lake of Hallwyl, of Sempach, several of the Italian lakes (Iseo, Orta), and many others. In fact, most of the valleys descending from the Alps have, or have had, a lake where they open on to the Plain.

4. The fourth class of lakes were once even more numerous in Switzerland than at present. As cases of lakes due to rockfalls, I may mention the Törler See, near Zürich, and the Klön See in Glarus; among those due to river-cones the Sarnen See, and the lakes of the Upper Engadine; and as instances of lakes dammed back by glaciers the Lake of Tacul on the Mont Blanc range, and the Merjelen See, which is dammed back by the Aletsch glacier. In our own country the margins of such an ice-dammed lake form the celebrated "parallel roads of Glenroy."

5. Loop lakes occur along the course of many large rivers. The stream begins by winding in a loop which almost brings it back to the same point. The narrow neck is then cut through and the loop remains as a dead river channel, or "Mortlake." Again, when an island is formed in mid-channel, one of the side streams is often cut off, and forms a curved piece of standing water.

6. Subsidence lakes, as already mentioned, occur principally in Triassic areas. The gypsum or salt is dissolved away in places, and eventually the ground gives way, leaving funnel-shaped hollows.

Such a pool was actually formed near the village of Orcier in the Chablais in the year 1860. There had previously been a strong spring giving rise to a stream. Suddenly the ground fell in, forming a pond about 20 metres long and 8 wide. Three fine chestnut trees were engulfed, and the pool was so deep that at 20 metres no bottom was found, nor were even the tops of the trees touched.[1]

These hollows are generally small, though in some cases, as for instance the Königs-See, the Lakes of Cadagno and Tremorgia in the Ticino, they are of considerable dimensions. Our Cheshire Meres are mainly due to the same cause.

7. Lakes occupying craters are far from infrequent in Volcanic regions, as for instance in the Auvergne, the celebrated Lake Avernus in the district of Naples, and the Maare of the Eifel. There are, however, no crater lakes in Switzerland.

8. As regards the greater Swiss lakes there has been much difference of opinion.

Ramsay and Tyndall maintained that they were rock basins excavated by glaciers.

Mortillet and Gastaldi[2] have suggested that the valleys were in pre-glacial times filled with alluvium, and that this soft material has been ploughed away by the glaciers.

"That glaciers rub down rocks," says Sir

[1] Favre, *Rech. Geol.* vol. ii.

[2] "Sur l'affouillement glaciaire," *Atti della Soc. Ital.* 1863.

A. Geikie, "is demonstrated by the *roches moutonnées* which they leave behind them." That they can dig out hollows has been denied by some able observers, but that they can do so to some extent at least, seems to be proved by the way in which the ice-striae descend into and rise out of rock basins.

"Taking the case of a glacier," says Tyndall, "300 metres deep (and some of the older ones were probably three times this depth), and allowing 12·20 metres of ice to an atmosphere, we find that on every square inch of its bed such a glacier presses with a weight of 486,000 lbs. With a vertical pressure of this amount the glacier is urged down its valley by the pressure from behind."[1]

Indeed, it is obvious that a glacier many hundred, or in some cases several thousand, feet in thickness, must exercise great pressure on the bed over which it travels. We see this from the striae and grooves on the solid rocks, and the fine mud which is carried down by glacial streams. It is of quite a different character from river mud, being soft and impalpable, while river mud is comparatively coarse and gritty.

The diminution in the rapidity of motion of a glacier at the sides and near the bottom, which has been sometimes relied on as

[1] Tyndall, "Conformation of the Alps," *Phil. Mag.* Oct. 1869.

evidence that glaciers cannot excavate, shows on the contrary how great is the pressure.

The question has been sometimes discussed as if the point at issue were whether rivers or glaciers were the more effective as excavators. But this is not so.

Even those who consider that lakes are in many cases due to glaciers might yet admit that rivers have greater power of erosion. There is, however, an essential difference in the mode of action. Rivers tend to regularise their beds; they drain but cannot form lakes. As Playfair long ago pointed out,[1] a lake is but a temporary condition of a river. Owing in fact to rivers, lakes are mere temporary incidents. The tendency of running waters is to cut through any projection, so that finally its course assumes some such curve as that in Fig. 47, from the source to its entrance into the sea.

The existence of a hard ridge would delay the excavation of the valley; above it the slope would become very gentle, but no actual basin could be formed; we should have some such section as in Fig. 67. The action of a glacier is different; it picks out as it were the softer places, and under similar circumstances basins might be formed above the harder ridges as shown in the dotted lines, D, D.

In many of the Swiss valleys the pressure

[1] Playfair's *Works*, vol. i.

of the ice on its bed must have been very great. The Rhone glacier not only occupied the basin of the Lake of Geneva, but rose on the Jura to a height of 760 metres. The lake is 309 metres deep, so that the total thickness of ice must have been over 1000 metres. The greatest depth of the lake is moreover opposite Lausanne, where the thickness of the ice would be at its maximum.

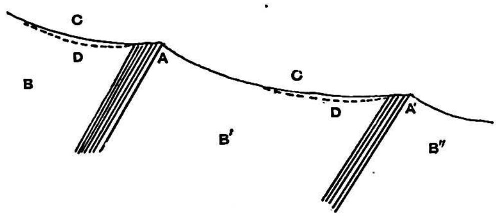


FIG. 67.—Diagram to illustrate the action of rivers and glaciers. A, A', Hard ridges; B, B', B'', Softer strata; C, C, Slope of running water; D, D, Slope of ice.

Moreover, the depth in proportion to its size is quite insignificant; Fig. 68 shows the height of the mountains, the thickness of the ice at the time of its greatest extension, while the dark line below gives the relative depth of the water, showing that after all the Lake of Geneva is really but a film of water.

There are, however, strong reasons against regarding glaciers as the main agents in the formation of the great Swiss and Italian lakes; and Swiss geologists are not generally disposed to accept this as a sufficient explanation. They admit that glaciers grind and smooth the rocks over which they pass, but deny that they effectively excavate.

The Lake of Geneva, 375 metres above the sea, is over 309 metres deep, and if we allow for the accumulation of sediment, its real bottom is probably below the sea level. The Italian Lakes are even more remarkable. The Lake of Como, 199 metres above the Sea, is 414 metres deep. Lago Maggiore, 194 metres above the Sea, is no less than 655 metres deep.

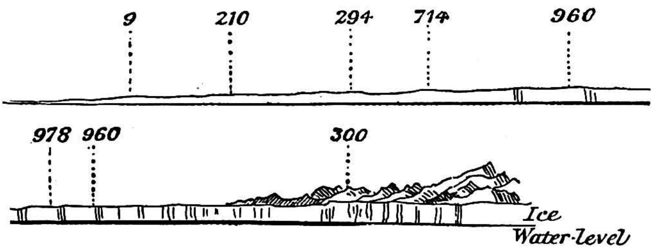


FIG. 68.—Diagram Section along the Lake of Geneva. The dark line shows the relative depth of the water.

The difficulty thus arising, moreover, is not so much the absolute depth, as the absence of relative height above the Sea, so that there would be no sufficient fall to carry off the water.

Even if we suppose that the Sea came up to Lyons, still the distance from Lausanne being 180 km., the Lake must have been raised 300 metres to give even a minimum fall of 2 per cent.[1]

[1] Forel, *Le Léman.*

In the valley of the Rhone the upper level of the ice had a slight but regular slope. At Schneestock the upper limit was at a height of 3550 metres, at Leuk 2100, at Morcles near St. Maurice 1650 metres. But at Chasseron on the Jura the height is now 1410 metres, at Chasseral 1306, on the Salève 1330. This gives a slope of $2\frac{1}{2}$ to 3 per cent only. Now in the present Swiss glaciers the slope is about 6 per cent. That of the glacier of the Aar, which is the least inclined, is 5 per cent. No doubt the greater the glacier the less is the inclination at which it can move. Still a slope of 3 per cent would seem quite inadequate. If, however, we suppose that the Alps had a relative greater altitude of say 1000 metres the difficulty would be removed, and the glacier would have a sufficient fall.

These and other considerations have led gradually to the opinion that while the valleys occupied by the Swiss lakes were mainly excavated by running water, the lakes themselves are due to a change of level which has raised parts of the valleys as compared with the river courses nearer the mountains.

Prof. Heim has suggested that the compression which elevated the Swiss mountains and piled, as we have seen (p. 66), more than double the original weight on this portion of the earth's surface, led to the formation of the great lakes. The mountain mass thus concentrated on a comparatively small area would from its enormous weight tend to sink somewhat into the softer magma below, which of course would have had in this respect the same effect as if the surrounding country had risen. The result would be to dam up the rivers and fill the valleys. For instance, in the Lake of Lucerne the bottom of the Bay of Uri is almost flat; it is evidently a river valley which has been filled with water.

In fact, speaking generally, the great Swiss lakes are drowned river valleys.

The relative subsidence of the mountains is no mere hypothesis.

There are, as we shall see, strong grounds for believing that the country round Geneva has been recently raised.

The old river terraces of the Reuss can still be traced in places along the valley near Zug. Now, these terraces must have originally sloped from the upper part downwards, that is to say, from Zug towards Mettmenstetten. But at present the slope is the other way, *i.e.* from Mettmenstetten towards Zug. From this and other evidence we conclude that in the direction from Lucerne towards Rappersdorf there has been an elevation of the land, which has dammed up the valley, thus turned parts of the Aa and the Reuss into lakes, and, as we shall see, considerably changed the course of the river.

Again, Professor Heim has pointed out that there has been a comparatively recent elevation, even since the commencement of the Glacial period, along a line traversing the Lake of Zürich. This is shown by the fact, that while the lower terraces follow the general slope of the valley, the upper glacial deposits present for some distance a reverse inclination. M. Aeppli in his recent work[1] has described them in more detail. They are seen on both sides of the lake, between Horgen and Wädenschweil on the one side, and between Meilen and Stäfa on the other. They do not, however, exactly correspond on the two sides of the lake, because the zone of compression crosses the lake diagonally, commencing more to the south on the east side. For the same reason, while the compression has on the east side made the terraces slope towards the lake, on the west the slope is towards the hill. This curious fact was very difficult to account for, but is satisfactorily explained by the inversion of the terrace.

I had the great advantage of visiting the terraces on the west of the lake under the guidance of Professor Heim, and looking across we could clearly see those on the east side also.

Looking to other countries the case of the Dead Sea is very suggestive. From its southern end a long depression leads southwards;

[1] *Beitr. z. Geol. K. d. Schw.*, L. xxxiv.

it is evident that the Jordan once ran into the Gulf of Akaba and so to the Red Sea, and that a subsequent change of level has created the Dead Sea, which has a depth of 396 metres below the Ocean level.

The great American lakes are also probably due to differences of elevation. Round Lake Ontario, for instance, there is a raised beach which at the western end of the lake is 110 metres above the sea level, but rises towards the east and north, until near Fine it reaches an elevation of nearly 300 metres. As this terrace must have originally been horizontal, we have here a lake barrier, due to a difference of elevation, amounting to over 180 metres.

The next question which arises is as to the age of the lakes. The valleys are now regarded by most Swiss geologists as preglacial, but the lakes themselves originated after the retreat of the glaciers.[1]

If these views are correct the larger lakes north of the Alps may be divided into three classes.

Firstly, the lakes of the Jura,—those of Neuchâtel, Bienne, and Morat, which occupy synclinal valleys.

Secondly, those of Hallwyl, Baldegger, Sempach, Greifen, etc., which are moraine lakes, the dams at the lower ends being moraines.

[1] Penck, *Vergletscherung der Deutschen Alpen.*

Thirdly, those of Constance, Zürich, Walen, Zug, Lucerne, Thun, Brienz, and Geneva, which are to some extent indeed dammed up, but in which the lower ends of the valleys have risen relatively, and which are partly at least geotectonic lakes.

Dr. F. A. Forel has suggested[1] that this subsidence of the Central Alps also throws light upon the former extension of the glaciers. The present snow-line is at a height of say 2600 metres. If we assume the subsidence to have been 500 metres (which seems the minimum), and suppose that 900 metres have been since removed from the whole surface, certainly no exaggerated estimate, this would bring the snow down to the present line of 600 metres, which would involve a great extension of the Firn, and consequently of the glaciers. He considers that an elevation of 900 metres would bring the glaciers of the Rhone down again to the Lake of Geneva. The theory deserves careful study, but is open to the objection that the Glacial period is no mere local phenomenon, but seems to have affected the whole northern hemisphere.

In considering the great Italian lakes which descend below the sea level, one suggestion has been that they are the sites of the ends of the ancient glaciers, and their

[1] *Le Léman.*

lower ends are certainly encircled by gigantic moraines. We must, however, remember that the valley of the Po is an area of subsidence and a continuation of the Adriatic, now partially filled up and converted into land by the materials brought down from the Alps. The plain of Lombardy is an area of subsidence, and we are tempted to ask whether the lakes may not be the remains of the ancient Sea which once occupied the whole plain. Moreover, just as the Seals of Lake Baikal in Siberia carry us back to the time when that great sheet of fresh water was in connection with the Arctic Ocean, so there is in the character of the Fauna of the Italian lakes, and especially the presence of a crab in the Lake of Garda, some confirmation of such an idea.

However this may be, the lower ends of the lakes have been dammed up by glacial accumulations, raising their levels considerably above the rim of the "rock basins."

Further evidence, however, is necessary before these interesting questions can be definitely answered.

The Color of the Swiss Lakes

Switzerland owes much of its charm to the lakes, and the lakes owe their beauty in great measure to their exquisite coloring. In this respect they differ considerably: the Lake of Geneva is blue, but most of the Swiss lakes are more or less green, and some brownish. What is the reason of their difference?

The blueness is not due to, though it may be enhanced by, the reflection of the sky. Pure water is of an exquisite blue. Of all the Swiss lakes the Lake of Lucel in the Val d'Herins is perhaps the clearest, and it is of a lovely blue. Various suggestions have been made to account for the green color of some lakes. The probable explanation appears to be that suggested by Wettstein, and ably supported by Forel,[1] namely, that the blue is turned into green by minute quantities of organic matter in solution. Forel took water from several lakes, thoroughly filtered them, but they retained their color, showing that it was not due to particles in suspension. He then took a block of peat, and infused it in water, thus obtaining a yellow solution. By adding a small quantity of this to the blue water of the Lake of Geneva, he was able to obtain a green water, exactly similar to that of the Lake of Lucerne.

He refers as a test case to the sister Lakes of Achensee and Tegernsee in the Tyrol. The basin of the Achensee is free from peat, in that of the Tegernsee peat mosses cover a large space. The former is a brilliant blue,

[1] *Le Léman*, vol. ii.

the latter a lovely green. He concludes, therefore, with Wettstein that the bluest lakes are those which are the purest; while green lakes contain also a certain quantity of vegetable matter, or peat, in solution.

This is, however, by no means the only cause to which water owes a green hue. Shallow water over yellowish sand is green by the reflection of the yellow light from the bottom. Again, after storms the water is often rendered thick and turbid. After the coarser mud has subsided the finer impalpable particles give the water a greenish hue, which, however, is only temporary, though it may last for some time. Finally, the water is sometimes colored green in patches by microscopic algæ.

But though the blueness of lakes and seas is not owing to reflection from the blue sky, the brilliancy, beauty, and variety of tone and tints, the play of color to ultramarine and violet, the constant changes and patterns varying with every breath of wind, the life and glory and beauty of the lakes are entirely due to the light of the sun.

The Beine or Blancfond

If, on a fine, still day, we look down the Lake of Geneva from some neighbouring height, we see the azure blue of the deep water fringed by a clear gray or greenish margin. This is the "Beine" or

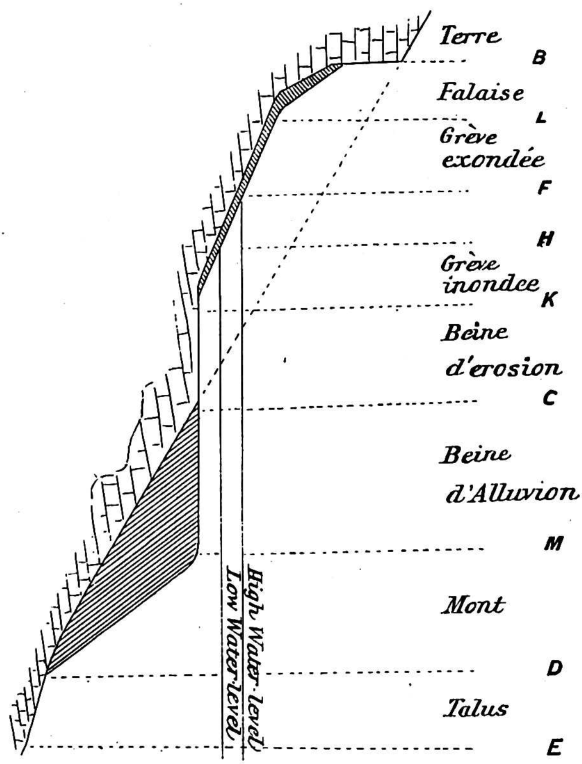


FIG. 69.—Diagram of the side of a Lake.

"Blancfond" where the shallowness of the water renders visible the gray or yellowish tint of the bottom. Such a shallow fringe or margin encircles many of the Swiss lakes, and may be explained as follows: The waves gradually eat away the bank, giving rise to a small cliff and talus (Fig. 69). The loose stones and sand are gradually rolled downwards, forming a slightly inclined terrace (Fig. 69, K, M) which finally ends in a steep slope. This terrace is known as the Beine or Blancfond. The depth of the Beine depends on that to which the water is agitated by the waves; it is less, therefore, in sheltered, and greater in exposed, situations. In the Lake of Geneva it ranges between 1 and 4 metres. It falls into two parts, the inner (K, C) due to erosion, and the outer (C, M) to deposition. The inclination of the outer slope depends on the nature of the materials; the finer they are the gentler it is.

The ancient Swiss Lake Villages were constructed on the Beine, and this shows us how constant the level of the great Swiss lakes must have been for many centuries or even some thousands of years. Many of the lake villages belong to the Stone Age, and the stumps of the piles on which they were built still remain.

The platforms could not, of course, have been constructed over water more than at the outside 5 metres in depth, so that during this whole period the level of the lakes must have been practically what it is now. Indeed, the structure of the Beine itself shows that the level must have remained approximately the same for a very long period.

CHAPTER X

ON THE INFLUENCE OF THE STRATA UPON SCENERY

THE character of Swiss scenery depends mainly on denudation and weathering, modified by the climate, the character, the chemical nature, the height, and the angle of inclination, of the rocks.

The total thickness of the sedimentary rocks has been estimated roughly at 200,000[1] feet, and as the whole of this was deposited in seas or lakes and was derived from former continents, we see how enormous the amount of denudation must have been, especially if we bear in mind that much of it has been washed down and deposited, then raised and afterwards washed down again; some of it moreover several times.

The principal forces which have disintegrated rocks are—(1) Water; (2) Changes of temperature; (3) Chemical actions; (4) Vegetation.

[1] Many of the beds, however, are not represented in Switzerland.

There are few rocks which are not more or less alterable by, or soluble in, water. It soaks in and filters through innumerable crevices, dissolving some substances, especially when it is charged with carbonic acid, and leaving others. It also acts mechanically, for as it expands when freezing, it splits up even the toughest rocks, if only there are any crevices into which it can enter. In a dry climate, therefore, the slopes will generally be steeper than in a more rainy region. Even in the absence of water, changes of temperature have a considerable effect owing to the fractures which they produce by the successive contractions and expansions to which they give rise.

These, however, though the principal, are by no means the only factors in denudation. The roots of plants, for instance, have a considerable effect, insinuating themselves into the smallest crevices and, as they expand with growth, enlarging them by degrees. Yet, on the whole, the action of vegetation is conservative. It absorbs much of the rainfall, and the formation of torrents is thus greatly checked. Some of the French Alpine districts, and much of Northern Africa, have suffered terribly, and in fact been reduced almost to deserts, by the reckless destruction of forests.

Different kinds of rocks are very differently affected by atmospheric influences.

Siliceous rocks are liable to disintegration by weather; but, on the other hand, the separate grains of sand or quartz are not only insoluble, but offer great resistance to mechanical action. Water, especially if charged with carbonic acid, can dissolve some Silica, but the quantity is insignificant.

Calcareous rocks are much more readily attacked. They generally contain some alumina and siliceous nodules, which remain as a reddish clay with flints after the calcareous matter has been removed.

Argillaceous rocks cannot be dissolved, but they are in many cases readily reduced to fine particles and then easily removed. They generally contain some calcareous material, and when this is washed away, pores and hollows are left which let in moisture. Even when compressed into Schists they often yield to the influence of moisture, and if sufficiently saturated sink into the form of mud.

Along the sides of valleys calcareous rocks often present steep, even vertical, faces (see Fig. 44, Valley of Bienne). Sandstones and Granite are generally less bold, and marly beds assume still more gentle slopes. The behaviour of argillaceous beds is more dependent on circumstances; if they are fairly dry they bear themselves well, but if they become wet they are very perishable.

So varied are the conditions that every mountain, even if the top only is visible, has a character and individuality of its own.

"Le profil de l'horizon," says Amiel, "affecte toutes formes: aiguilles, faîtes, créneaux, pyramides, obélisques, dents, crocs, pinces, cornes, coupoles; la dentelure s'infléchit, se redresse, se tord, s'aiguise de mille façons, mais dans le style angulaire des sierras. Les massifs inférieurs et secondaires présentent seuls des croupes arrondies des lignes fuyantes et courbes. Les Alpes sont qu'un soulèvement, elles sont un déchirement de la surface terrestre. Le granit mord le ciel et ne le caresse pas. Le Jura au contraire fait comme le gros dos sous le dôme bleu."

Not one of these varied forms is accidental. Every one of them has its cause and explanation, though we may not always know what it is.

The same configuration will of course look very different from different points of view. What seems like a sharp point is often the end of a ridge. The sedimentary rocks of the northern Alps generally present one very steep side and thus sloping away more or less gently (Rigi, Pilatus, Bauenstock, Sentis, Speer, etc.), often in a succession of steps which are rendered conspicuous by lines of snow, having therefore what has been happily called by Leslie Stephen a desk-like form (Fig. 84). They present broad, gently inclining plateaux, ending suddenly in a steep, almost perpendicular, precipice, which towers like a wall over the valley, such as the Diablerets, Wildstrubel, Gadmerfluh, Claridenstock, Tödi, Vorab, Balmhorn, Doldenhorn, Blümlisalp, etc.

In such districts still further denudation gives rise to ridges terminating in towers and teeth, sometimes of terrific wildness, as in the Engelhörner, or in the chain of the Gspaltenhorn. The calcareous Alps are also characterised by the numerous terraces, bands, pillars, and cornices. The precipices, as for instance on the Jungfrau and the great Wall of the Bernese Oberland, sometimes reach 2000 metres.

We might at first be disposed to anticipate that from their hardness and toughness the Crystalline rocks would be less liable to denudation than the calcareous. And in a sense this is true. In consequence however of these very qualities the drainage in Crystalline districts is mainly superficial, while in calcareous regions much of the rainfall sinks into the ground and is carried off by subterranean passages. In our own country we know that the chalk uplands, though cut into along the margins by deep combes, are seldom intersected by valleys, and almost all our railway lines leaving London have been compelled to tunnel through the Chalk. So also in Switzerland the calcareous strata form long continuous ridges, of which the great wall of the Bernese Oberland is a marvellous example.

Another reason for the extremely bold character of the calcareous mountains is that such strata are extremely stiff, and where argillaceous rocks would gradually bend, they break away and thus give precipitous cliffs.

It was at one time supposed that each kind of rock gave its own special mountain form. Such was the view, for instance, even of excellent observers, such as L. v. Buch and A. v. Humboldt.

It would, however, be quite a mistake to suppose that particular contours always indicate the same kind of rock. On the contrary, we find the same forms in different rocks, and different forms in the same description of rock. They depend greatly on the hardness of the rock, and on the angle at which it stands. Thus tower-like forms occur in Granite, Amphibolite, Sandstone, Conglomerates, Hochgebirgkalk, Dolomite, etc. The desk-like form which is so frequent in calcareous strata (see, for instance, Fig. 70 on the right hand side) occurs also in some districts of Gneiss or of Nagelflue, as, for instance, at the Rigi (Fig. 84). On the other hand, the same rock may give a very different landscape. Thus Granite often assumes rounded outlines, but often also gives wild ridges of teeth and needles.

Gneiss summits with gently inclined beds are less steep and less pointed, while calcareous rocks if hard and steeply inclined assume not only wild but grand outlines. The Eiger is perhaps the finest type of a calcareous mountain.

On the other hand, in any given district similar geological structure will generally give similar scenery.

As a rule steeply inclined strata produce bold outlines, while those which are more horizontal give a tamer scenery.

Still, where the rocks are very resistent, and denudation has been great, even horizontal strata may give very bold forms; of this we have a remarkable instance in the Matterhorn, a mountain left between two valleys, where the strata are but slightly inclined, and yet owing to their position and hardness give us the boldest and steepest mountain of the whole chain. In districts of the softer rocks we naturally miss the bold, steep precipices, the jagged ridges, and noble peaks, and must content ourselves with smiling landscapes and gentle undulations.

Another reason which affects the landscape in districts of sedimentary and Crystalline rocks is that the former crumble away more rapidly, and thus more quickly lose the rounded surfaces due to ice action. Thus, as we ascend the valley of the Reuss, where we leave the softer strata and enter the district of Gneiss, we also commence a scenery of knolls rounded by ice.

In calcareous districts "weather terraces" form a special feature (Figs. 44, 45). They are due to a succession of rocks of different hardness and toughness, so that some strata weather back more quickly and take a gentler slope than others. Crystalline rocks are generally more homogeneous, weather more evenly, and consequently present more regular and continuous slopes. The Bristenstock, for instance, which towers over the Reuss, is a beautiful example. For a height of 2500 metres it presents an unbroken slope at an angle of 36°. Weather terraces are particularly conspicuous in certain lights, and especially in winter when there is snow on the gentler slopes. Even in summer, however, the contrast of vegetation is often striking, some lines being marked out by luxuriant grass or bushes, while others are comparatively bare. On Granite or Gneiss a good mountaineer can go almost anywhere, while in mountains of sedimentary strata he is stopped from time to time by an impassable precipice.

On the whole, when seen from a distance, the forms of the sedimentary mountains are more marked, more broken, and, so to say, more individualised.

The central Crystalline "massivs" present very different forms. The desks, terraces, pinnacles, and cornices disappear, and we have noble pyramids. The ridges, moreover, are more jagged and serrated. Fig 70 shows the contrast of a jagged Crystalline ridge and

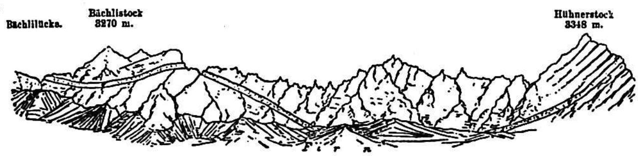


FIG. 70.—Ridge of the Gauli. Profile of the ridge from the Bächlistock to the Hühnerstock, showing the peaks of the granite rock and the desk-like slope of the calcareous strata forming the Hühnerstock.

the desk-like form of the calcareous strata on the right (Hühnerstock).

In the splendid panorama seen from Bern the Crystalline mountain peaks (Finsteraarhorn and Schreckhorn, Breithorn, Tschingelhorn, etc.) can readily be distinguished from the calcareous mountains (Blümlisalp, Doldenhorn, Aletsch, etc.). The difference of character is also well seen as we ascend the valley of the Reuss from Fluellen to Andermatt.

On the whole, the calcareous chains of the Alps are wilder, the Crystalline grander.

Typical Gneiss often gives gentle rounded outlines. On the other hand, Sericitic Gneiss and Mica Schists, which often closely resemble Gneiss, show generally great readiness to fracture in sharp, knife-edge ridges, and very wild if perhaps less sublime forms. The Bernese Oberland owes both its great average height and the variety of its scenery to the combination of Gneiss with calcareous strata. The consequence is that it does not form an uniform range, like the Pyrennees, but a succession of individual mountains, presenting some of the noblest forms. In this district the Gneiss is inverted over the secondary strata, which it thus serves to protect. The result is that the weathering forms of both strata come into play, and thus produce endless variety.

Granite is regarded by poets as peculiarly resisting, and it is described as

> Stern, unyielding might,
> Enduring still through day and night
> Rude tempest shock and withering blight.

As a matter of fact, however, granites, as a rule, are very susceptible of disintegration. Granite mountains tend to gentle, rounded, and massive forms.

Rain, and especially water charged with carbonic acid, acts on Granite profoundly. In many quarries where it looks solid enough it will be found to be disintegrated to a considerable depth, and even changed into a loose sand. This is due to the Felspar; the alkaline salts of soda and potash being decomposed by the carbonic acid, leaving the Silicate of Aluminium, the Mica, and the Quartz. It seems at first inconsistent with this that Granite ridges are often peculiarly jagged, but in such cases the Granite is steeply inclined, and the debris are removed as they form.

In other cases Granite shows a tendency to weather in flat, convex shells, and to split vertically in two or often three different directions: it is divided, moreover, into horizontal layers at more or less regular intervals, thus forming rhomboidal blocks or pillars. Granite possessing this structure often assumes very bold, wild forms.

Protogine, though so similar to granite, generally gives a different scenery. It breaks up more readily into Aiguilles, and the stratification is more marked. The Mont Blanc range, for instance, which consists of vertically structured Protogine, has a different aspect from the chains which are composed of true granite.

The "Aiguilles" formed by Crystalline Schists, as for instance in the Mont Blanc district, at first sight resemble dolomite peaks. The transverse lines, however, are not continuous, and the summits are even more pointed, though in many cases, as, for instance, the Aiguille de Charmoz, what seems a pointed needle is really a long, narrow crest. The materials are among the very hardest in existence.

Hornblende schist is sometimes quite pale, sometimes very dark. It often becomes reddish by decay of the ferrosilicate, so that many mountains of this rock are known as the Rothhorn, Rothfluh, etc. It forms bold, sharp ridges, and torn, wild, pointed peaks.

Porphyry, though rather rare, forms an extensive bed in the neighbourhood of Botzen, occupying an irregular strip, running from north to south, some 40 miles long by 12 wide, through which the outlet of the Adige has been cut. The great rounded walls of dull purplish-red rock, clothed in many places with brushwood, and supporting large upland plateaux of the richest herbage, produce a scene of singular luxuriance and beauty, especially when their tints are heightened by the glow of the setting sun. Beautiful as they are at all times, there is then something almost unearthly in their splendour; and no one who has not made an evening journey from Meran to Botzen, or from the latter place by the gorge of the Kuntersweg, knows what treasures of color the Alps can afford.

Dolomite is a magnesian limestone. The aspect of Dolomite mountains has been most aptly compared to ruined masonry, and it is often difficult to believe that the summits of dolomite peaks and ridges are not crowned by crumbling towers, castles, and walls built by man.

A square columnar formation is characteristic. The whole of the face shows transverse and vertical marking, the transverse lines running more or less continuously across the whole. The jagged outlines of the crests form a principal feature for their recognition. The outline is usually "embattled," to borrow an expression from heraldry. The colors are marvellously beautiful—cream color and gray predominate, but not to the exclusion of others. In the glow of sunset they are almost unearthly.[1]

The Upper Jurassic gives valleys a very characteristic aspect. It assumes a steep slope of from 40° to 60°. If the inclination is not above 45° it becomes covered with vegetable soil and often clothed with fir; but the steeper slopes are bare and arid, and are known as Châbles or ravières, giving an aspect of ruin and desolation, forming often a strong contrast with the brilliant vegetation below.

[1] C. T. Dent, *Mountaineering*, Badminton Library.

In calcareous districts the surface is sometimes quite bare and intersected by furrows attaining a depth of several, sometimes even as much as 30 feet.

A good illustration is to be seen above the hotel at Axenstein on the Lake of Lucerne, where a portion of the rock has been uncovered. Another is at the Kurhaus on the Brunig.

Rollier refers to a great erratic on the Lapié of Bonjean near Bienne, which has protected the rock below it, so that it rests on a flat surface in the middle of the lapié. The Hohle Stein near Donanne is another case of the same kind.

The Karren are extremely barren, but the rock generally contains some small percentage of clay, which is washed into the hollows and supports some scanty vegetation.

The Flysch gives gentle uniform slopes. The Nagelflue, in the familiar case of the Rigi, is an illustration of the desk-like form, with a steep escarpment towards the Bay of Küssnach and a gentle slope following the inclination of the beds from the Rigi Kulm to the Schiedeck. In other cases the Nagelflue gives a very complicated relief, sometimes forming mountain knots from which valleys radiate in all directions. Deep gorges, with perpendicular, almost overhanging, bellied walls, and abrupt terminations also frequently occur in Nagelflue districts, as for instance to the north of the Lake of Thun, on the Speer, and elsewhere.

Glaciated regions present us two totally distinct types of scenery: a central or upper of bare barren rock with rounded outlines (Fig. 32), and a peripheral ring of debris in scattered heaps and long mounds.

These morainic deposits give a peculiar character to the scenery: the country is very diversified and irregular, thrown into confused heaps and depressions, which, as the lower or ground moraine is very impervious, often contain small lakes. They occur especially in well-watered districts, and the rich network of rivers often take very devious courses. Desor has happily characterised such a district as "un paysage morainique."

The scenery is again affected very much by different strata in consequence of their influence on streams and springs. For instance, in a country of hard impervious rock we have numerous little runnels which gradually unite into larger and larger streams. On the contrary, in a calcareous district, especially if fissured, we find, as for instance in parts of the Jura and elsewhere, large districts with very few streams, and here and there copious springs, where the water is brought to the surface by some more impervious stratum. A glance at any geological map will show, for instance, that the districts occupied by the Upper Jurassic rocks are especially waterless, there being many square miles without even the smallest rivulet.

The distribution of springs naturally affects that of villages. Thus in several of the valleys of the Jura we find a row of hamlets along the outcrop of the impervious Purbeck strata.

The influence of different rocks upon vegetation is another way in which they affect the character of the scenery. The principal contrast is between Crystalline and calcareous strata.

Cargneule gives fertile pasturage, as do the Lower and Middle Jura owing to the quantity of Marl they contain.

The Cretaceous rocks furnish sweet but not abundant herbage, and the Lias is but moderately favourable to vegetation. The Urgonian districts are arid and barren, and can be distinguished even at a distance from the Neocomian, which bears a luxuriant vegetation.

Flysch supports a vegetation, vigorous indeed, but of comparatively little value; the slopes generally bear dry grass and heather, while the flat ground is marshy.

Moraines often bear high Alpine plants, not so much from any peculiarity of soil, as because of its coming from the heights.

Screes are generally bare from the continuous movement, which does not give plants time to grow.

Rockfalls

Falling stones constitute one of the greatest dangers of the Alps. Tyndall was injured, and Gerlach killed by one. Many couloirs cannot be ascended without much risk, and the ancient passage up Mont Blanc, first discovered by Balmat, has been abandoned for another longer, but safer, route. Many of the steeper valley sides, as, for instance, those between Martigny and the Lake of Geneva, are furrowed by stone streams, which, like those of water, have their collecting ground above their regular channel, and a cone of deposit below, which, however, stands at a steeper angle than that of a torrent. Many rockfaces have a continuous talus or scree of fallen stones at the base, which takes an angle of about 30°, and in some cases has almost climbed up to the summit. Along the valleys of the Niremont—Pleiades which abut on the Lake of Geneva at Montreux, the debris from the two sides meet in the middle, and attain a great thickness. One of the finest examples is that at the foot of the Diablerets, which rises from 2035 metres to about 2400 metres.[1]

[1] Renevier, *Beitr. z. Geol. K. d. Schw.*, L. xvi.

The Glärnisch is nearly surrounded by rockfalls on its northern and eastern sides. They are mostly of interglacial age, and to one of them the Klönthalsee is due.

In the debris of rockfalls the edges of the stones remain fresh and angular, on many of them the surfaces show marks of blows, rubbing, hollows, and impressions, where they clashed against one another during the descent. They lie in wild confusion, large and small together, from fine dust up to rocks larger than a house. In some cases the originally loose materials have been subsequently cemented together into a breccia. The surface is very irregular, and often contains lakes, as, for instance, at Sierre in the Valais, and Flims on the Rhine.

The rockfall of Goldau from the Rossberg which occurred in 1806, which has been figured by Ruskin,[1] is well seen on the St. Gotthard line, between Lucerne and Brunnen.

Even more destructive was that of Piuro (Plurs) in the Val Bregaglia in 1618. After heavy rain a great part of the side of Mont Conto fell suddenly into the valley, and of 2000 inhabitants very few escaped.

At Flims ("Ad flumina," so called from the number of springs and streams) the road rises far above the Rhine and passes over an ancient rockfall, the greatest in all Switzer-

[1] *Modern Painters*, vol. iv.

land, far surpassing that of Goldau. It blocked up the valley, thus forming a lake, and the Rhine has not even yet cut completely through it. The debris rise to a height of 700 metres on both sides of the river. They consist mainly of Malm interspersed however with blocks of Dogger, Verrucano, etc., and fell from the Flimserstein. The fall appears to have taken place between the first and last great extension of the glaciers. As in all rock-falls the surface is very uneven; and in the hollows are several beautiful lakes. The isolated eminences in the valley below Reichenau are probably portions of another rockfall.

Among other great rockfalls may be mentioned those of Antrona Piana on the 26th June 1642, which destroyed the Parish Church and many houses, causing also much loss of life: those of the Diablerets in 1714 and 1749, of Montbiel in Prättigau in 1804, and the Dents du Midi in 1835, and that of Elm in 1881. The pretty little lake of Chède, on the road between Geneva and Chamouni, was filled up by a rockfall in the year 1837.

Nor must rockslips pass altogether unmentioned. Sometimes the movement is continuous, though very slow. In the chains of the Gumfluh, between Château D'Oex on the Sarine and the Diablerets, which are composed of hard calcareous rock on which vegetation establishes itself with difficulty, the cone of talus descends slowly towards the valley almost like a river.[1]

Again at Soglio in the Val Bregaglia a mass of detritus which has itself fallen from the steeper precipices, was for a long time, and probably is still, slowly moving downwards. The firs which grow on it do not stand upright, but cross one another at various angles, some being almost prostrate. The rocks below (Gneiss and Mica Schist) are inclined so that the edges retard the movement, which would otherwise be quicker and more dangerous.

Theobald tells us that in the summer of 1861, at the time of the melting of the snow, he was on a geological excursion near the Schwarzhorn in the Grisons when he gradually became aware of a strange roaring and crushing noise all round him. At first he paid little attention to it, but he at length found that the whole surface on which he stood was slipping downwards. He escaped as quickly as he could, but the movement continued, and about a quarter of an hour afterwards a great mass, 20 to 30 paces in length, precipitated itself over a precipice.[2]

[1] Favre and S., *Beitr. z. Geol. K. d. Schw.*, L. xxii.
[2] *Beitr. z. Geol. K. d. Schw.*, L. ii.

Earth Pyramids

Whenever we have a deposit of comparatively loose material with hard blocks, or layers, there is a tendency to form earth pyramids, owing to the looser material being here and there protected by a more or less tabular block of hard substance. The most remarkable assemblage of such earth pillars is near Klobenstein, in the valley of the Katzenbach, near Botzen,[1] described and figured by Lyell; that of Useigne in the Val d'Herins is another classical example.

[1] *Prin. of Geol.*, vol. i.

CHAPTER XI

JURA

THE Jura forms a curve somewhat resembling that of the Alps, trending at first N. and S., and subsequently S.W. and N.E.

It falls into two well-marked divisions, the Tabular Jura and the Folded Jura.[1]

TABULAR JURA

The Tabular Jura consists of two comparatively small tracts, one to the N.E., the other to the S.W., which have escaped compression, and consist of approximately horizontal strata.

In Fig. 71 the ancient mountains of the Black Forest and the Vosges are shown on the N.E. and N.W. Between the two dotted lines is the area of subsidence now forming the valley of the Rhine. The Dinkelberg is a district south of the Black Forest, which has sunk to some extent, but not so much

[1] Müller, *Beitr. z. Geol. K. d. Schw.*, L. i.

as the Rhine valley. The Tabular Jura of Aargau lies south of the Dinkelberg, and the Elsgauer Tabular Jura south of the Vosges. Between them, south of the Rhine valley, the Jura is thrown into a succession of folds. The ancient crystalline rocks of the Black Forest and the Vosges are probably continued under

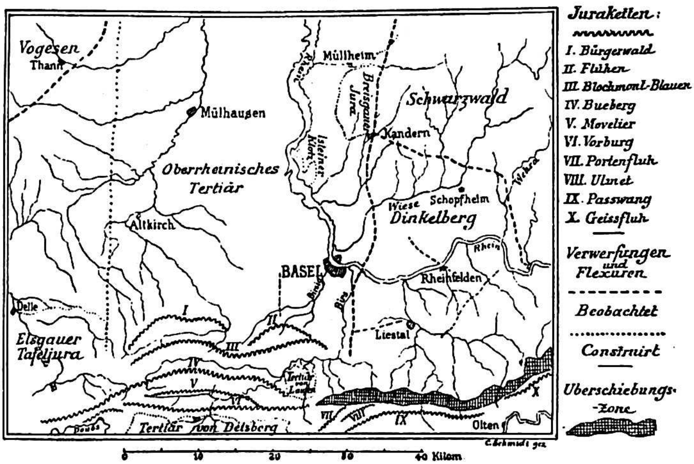


FIG. 71.—Environs of Bâsel. 1=1,000,100.

the Jurassic strata to the south, and, as Mülhberg suggests, may have protected them from being folded and contorted as they have been further to the south. It is interesting as confirming this view that the horizontal character of the strata ceases opposite the sunk area of the Rhine valley, and the foldings there reach northwards to the edge of the valley.

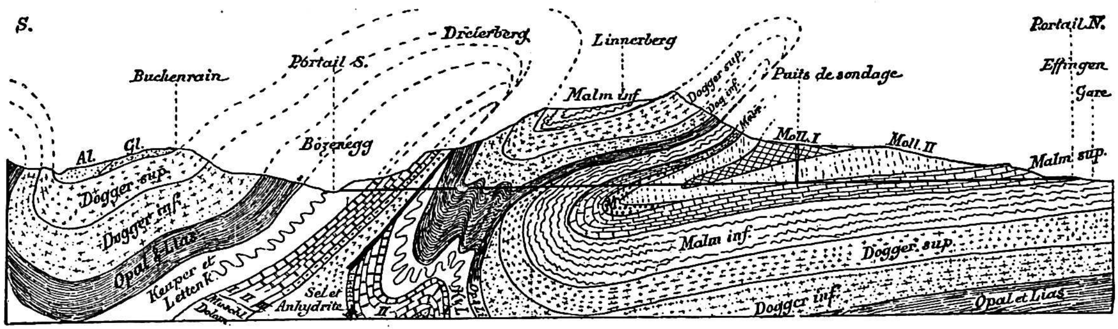


FIG. 72.—Profile of the Botzberg Tunnel.

At the line of contact of the "Tabular Jura" with the Folded Jura, the latter are generally thrust more or less over the edge of the tabular strata, as shown in the figure 72, which represents the junction of the two at the Botzberg tunnel, near Brugg.

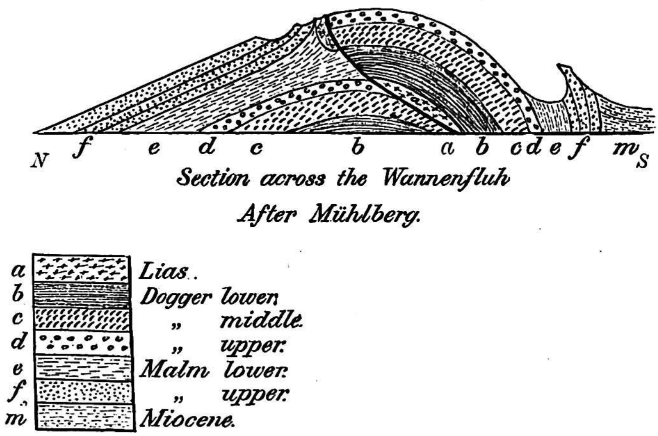


FIG. 73.—Section across the Wannenfluh.

Fig. 73 gives a section of the Wannenfluh, the mountain on the east of the cluse which leads from Balstatt to Oensingen between Soleure and Olten, and it is evident that the strata to the south have been thrust somewhat over those to the north.

This "Zone de recouvrement," as it is termed by the Swiss geologists, is shown by the belt marked with cross-lines in Fig. 71.

It extends from Meltingen (S.E. of Laufen) by Reigoldswil, Oltingen, and Botzberg, to near Baden in Aargau. The overthrust indicates that the pressure came from the south.

Folded Jura

The Folded Jura is thrown into some 160 undulations and about fifteen main folds nearly parallel to one another. These however do not extend the whole length of the district; they are most numerous to the S.W., where there are as many as twelve, but gradually coalesce towards the N.E., others from time to time making their appearance, but still the number gradually diminishing to a single anticlinal, which crosses the Reuss forming the Cluse south of Brugg, and finally disappears at Regensberg, to the north of Zürich.

The folds of the eastern Jura are the most intense, while those of the west again surpass those of the centre. In all cases the amount of compression is approximately the same—about 5000 metres, the folds increasing in intensity as they diminish in number.

This subdivision and reunion of folds which is so clearly visible in the Jura, is frequent also in the Alps, and indeed in folded chains generally.

A glance at any map will show that

the Jura is a succession of hills and valleys, running approximately S.W. and N.E. These ridges and depressions are mainly due to compression, and to the consequent undulations of the strata, as shown by Fig. 74, giving a section from N.W. to

FIG. 74.—Section across the Clos du Doubs.

S.E. a little south of Porrentruy, near the remarkable turn of the River Doubs and crossing both stretches of the river. It will be seen that the valleys are synclinals, and that in the valleys the action of water has been but slight.

The next figure (Fig. 75) represents a

FIG. 75.—Section from the Valley of Délemont to that of Moutier.

section across the Mont de Moutier, from the Valley of Délemont to that of Moutier, and we see that some of the highest ground is a synclinal.

Figure 76 gives a case of two neighbouring valleys, one of which (Le Locle) is a synclinal, the other (Entre-Deux-Monts) an anticlinal.

In both the cases above mentioned the configuration of the surface, the arrangement of hills and valleys, the direction of rivers and

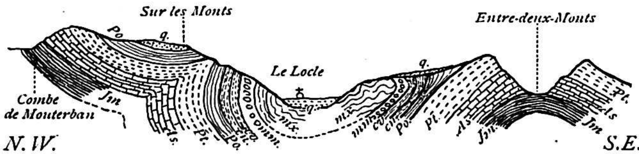


FIG. 76.—Profile of the Valley of Locle.

mountains, correspond closely with the geological structure.

Fig. 77 represents a section of the Vuache. It will be seen that the Vuache is the half of an anticlinal, the western part having subsided

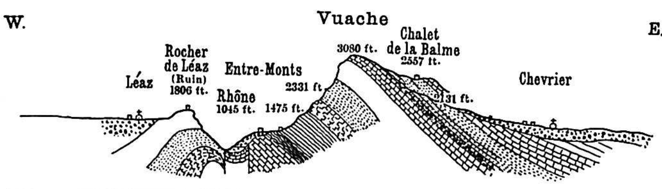


FIG. 77.—Section across the Vuache.

about 1000 m. The Rhone runs along the fault. In this case the fault is nearly vertical, but in others one side is thrust more or less over the other. In the Jura, faults generally, but not always, betray themselves on the surface.

The Salève (Fig. 78), which forms such a conspicuous object at Geneva, is an arch, fractured at the summit, and steeply inclined to the N.W.

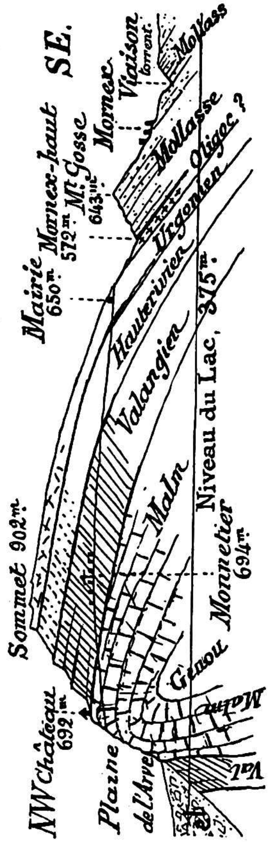


Fig. 78.—Transverse Profile of the Petit Salève. 1=25,000.

While river valleys, being due mainly to erosion, slope to one end, the valleys of the Jura are so entirely the result of geological causes that they are sometimes horizontal, or even lowest in the middle, and in several cases closed at both ends. The result is that they are often dry valleys, or contain streams running from the two ends towards the centre.

Thus between Biel and Delémont we have the Val de St. Imier, in which the Suze, running to the E., meets the stream which comes down the Combe de Péry, and the two together find an exit through the Cluse de Péry to Biel.

A little north is the Val de Tavannes, where again two streams, one from the N.E., and the other, the Birse, from the S.W. meet at Court,

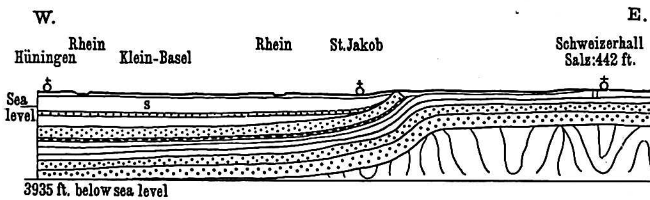


FIG. 79.—Section across the Rhine Valley.

and find an exit northwards by Moutier to Delémont. The valley of Delémont itself is another case. Two streams, one from the east, another, the Sorne, from the west, meet

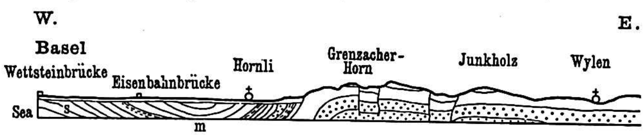


FIG. 80.—Section across the Rhine Valley at Basle.

the Birse near Delémont, and run through another cluse to the N.E.

The Jura is thus crossed by four principal transverse valleys or cluses.

The longitudinal valleys were probably filled at one time by mollasse, and some perhaps formed lakes, as, for instance, the flat plains near Pontarlier, Delémont, the Val St. Imier, etc. Between Delémont and Soleure are several ridges, which are cut through by the "cluses" of the Birse and the Sorne. If we imagine these "cluses" abolished, the result would be to form lakes; these would gradually fill up, and eventually run over where the "cluses" now are, which would thus be re-excavated. This throws light on the cases, not otherwise easily explicable, where in neighbouring and parallel valleys the streams run in opposite directions. The valley of Etraches, for instance, N.E. of Pontarlier, runs parallel to that of the Doubs, but the Etraches runs from N.E. to S.W., the Doubs from S.W. to N.E. Nay, the Doubs itself, after running north-eastward to St. Ursanne, between rocks 250 to 300 metres high, makes an extraordinary turn. Its course so far had been in the main to the N.E., but at St. Ursanne it turns to the W.S.W., enclosing a high ridge (Fig. 74) known as the Clos du Doubs.

The valley of the Rhine from Basle northwards is of comparatively recent origin, being due to a subsidence which has separated the Black Forest from the Vosges. Just south of Basle the anhydrite beds which at Bettingen are 400 metres above the sea level, have sunk at Hünningen to 600 metres below it, a drop of 1000 metres in about five miles.

At Basle the section is as in Fig. 79. Further north the sinking is more profound, and the strata are fractured (Fig. 80). At

Kandern the depression amounts to 1500 metres.

The sinking of the Rhine valley near Basle was no doubt a slow process. It probably began in the Glacial period, before which time the whole drainage of the country must (see *ante*, p. 192) have been entirely different from the present.

The eastern boundary of the Rhine valley subsidence is apparently continued along the cross line of Mümliswyl Balstall. The downthrow of the fault is here also to the west. Again, the western boundary of the Rhine valley, though this is more uncertain, may perhaps be correlated with the cross valleys which pass by Delle, Porrentruy, and St. Ursanne, continuing possibly by Sonceboz to Biel.

The selection of Pontarlier for the line of railway has been determined by one of the geological events which has most profoundly affected the chain of the Jura. The displacement, commencing in the direction of the valley of the Loue, and passing through it to the eastern end of Mont Tendre, has been utilised by rivers, roads, and railway lines. It passes nearly due S.N., and all the anticlinal and synclinal folds on the two sides of the line show a dislocation, sometimes amounting to 2 or 3 km.

The Jura is very poor in rivers and streams. It consists mainly of calcareous strata, often much fissured, so that the rain sinks into the ground and reappears often in copious springs —named from one of the most celebrated "sources vauclusiennes"—where the water is brought to the surface by some more impervious stratum.

In several cases the disposition of the ridges and the character of the rock is such, that the streams have no natural issue, and after a longer or shorter course under ground, reappear at some distance. Thus the Orbe commences in a closed valley. The upper part, or Vallée de Joux, is double, one branch being without any river, except a little streamlet which runs into the Lake of Ter. The southern is traversed by the Upper Orbe, which falls into the Lake of Joux, and its continuation, the Lake of Brenet. Neither of these has any open outlet, but the waters escape by an underground passage, and reappear above Vallorbes.

This had long been suspected, but was eventually proved in 1893 by M. Picard, who poured in some fluorescine, which after the lapse of 30 hours reappeared in the source of the Orbe.

Again the valley of La Brevine is a synclinal of Cretaceous rock, surrounded by Jurassic, and entirely closed. The waters escape through several swallow holes or "emposieux." These, however, sometimes get choked, and the valley is flooded.

It has been suggested, as already mentioned, that before the sinking of the Rhine valley at Basle, which opened a new route to the north, it belonged to the river system of the Danube; there is also some ground for thinking that at a subsequent period it continued its course W.S.W. to the Saône, and that the valley of the Doubs below St. Ursanne is in fact an old bed of the Rhine. This interesting point, however, can only be determined by further evidence.

The southern limit of the Jura forms the great mountain wall, which, from the Lake of Geneva north-eastwards to Bern, Freiburg, and Aarau, may be seen stretching along the north, without a break, from the Fort de l'Ecluse, where the Rhone crosses the Mont Vuache, to Montricher near La Sarraz.

Some districts of the Jura have suffered greatly from the reckless destruction of forests, as, for instance, parts of Mont Tendre, whose dry and barren slopes were once clothed with luxuriant vegetation. It is unfortunately becoming evident that much arable land and pasture which, at great labour and expense, have been formed out of the primeval forest, will, with perhaps even more, have to be re-afforested again.

The Jura mountains contain several interesting caves, often associated in popular tradition with the fairies, as the Temple aux

Fées near Longeaigues, the Grotte aux Fées near Vallorbes, the Beaumes de la Côte aux Feés, etc. The Grotte de Remonot on the Doubs was long used as a village church.

Near Moutier a crack in the Upper Jurassic beds, which was exposed in preparing the foundation for a church, was found to contain many bones of quadrupeds belonging to the Eocene period, including three species of Palaotherium. Similar fissures containing Eocene fossils have been met with at Egerkingen, Ober-Gösgen, and elsewhere, showing that dry land existed here during the Eocene period.[1]

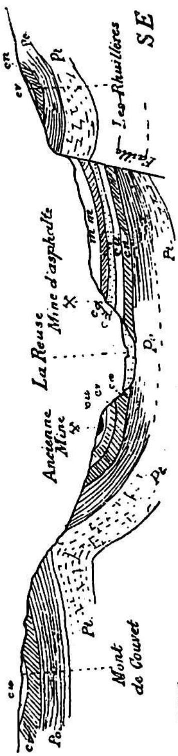


Fig. 81.—Profile of the Val de Travers. After Jaccard.

The celebrated asphalt of the Val de Travers (Fig. 81) comes mainly from Urgonian strata. The valley is a synclinal, bounded, however, on the S.E. by a fault, which brings the more recent strata, from the Portland Beds to the Mollasse, directly against the Malm.

[1] Müller, *Beitr. z. Geol. K. d. Schw.*, L. i.

As already mentioned, during the Glacial period the grand sheet of ice which spread over the whole central plain of Switzerland, rose to a great height on the slopes of the Jura. The glacier even rose over more than one of the cols, and streamed into the inner valleys as, for instance, by Romainmotier into the Val de Vaulion. The Val de Travers has long been celebrated for the number of erratic blocks which it contains. In many places the rocks are ground and polished by the glaciers.

The Rhine at Basle runs on a bed of gravel 30 metres at least in thickness, and the hills on each side are capped with a yellow, fine, sandy, marl known as "loess," up to a height of 100 metres.[1]

Most indeed of the valleys were once much deeper than they are now. The bottoms are filled up with gravel and alluvium, indicating the presence of bars which are now covered up. The alluvial deposits often attain a great thickness. Near Travers a proposed railway bridge had to be abandoned, from the difficulty of obtaining any sufficient foundation.[2]

LAKE OF NEUCHÂTEL

The Lake of Neuchâtel is about 24 km. in length, and 6 in breadth. It is 432 metres

[1] Müller, *Beitr. z. Geol. K. d. Schw.*, L. i.
[2] Jaccard, *Beitr. z. Geol. K. d. Schw.*, L. vi.

above the sea and 153 in depth. Unless therefore the gravel beds of the Aar are 500 feet deep it is also a rock basin. It is surrounded by marshes which used to cover 50,000 acres, but a good deal of the area has now been drained.

The Lake of Neuchâtel and of Bienne at one time formed a single sheet. Indeed, the former lake extended from Orbe on the west to Soleure on the east. The basin is formed by one, or rather two, of the longitudinal Jura valleys. I say two because a ridge of Marine Mollasse, commencing at the hill of Chamblon near Yverdun, runs along the centre of the lake, forms the Jolimont between the Lake of Neuchâtel and Bienne, and continues along the centre of the Lake of Bienne, forming a ridge over 400 feet in height, and appearing above the surface as the Isle de St. Pierre. In fact, if the level of the water was reduced the Lakes of Neuchâtel and Bienne would each be resolved into two narrow lakes; while if the water rose they would form a single sheet with the Lake of Morat.

CHAPTER XII

THE CENTRAL PLAIN

To the S.E. of the Jura is the great Central Plain of Switzerland, which is a plain however only in contrast with the mountains by which it is surrounded, and in other countries would be regarded as an elevated hilly region. Thanks to its geological and climatic conditions, it is one of the richest and most genial parts of Europe.

It extends in a S.W. and N.E. direction from the Lake of Geneva across that of Constance to Würtemberg, and has an average width of about 30 miles.

It is mainly formed of Miocene strata known as Mollasse; usually divided into—(1) Lower Freshwater Mollasse; (2) Marine Mollasse; and (3) Upper Freshwater Mollasse; which, however, according to Kaufmann, were in some cases being deposited simultaneously; no doubt there were several alternations of sea, marsh, and freshwater.

The Mollasse attains an unknown thickness. In parts of Vaud the upper beds alone reach over 1000 metres.

In fact, during the Miocene period, the country between the rising Alps and the Jura was a basin occupied sometimes by the Sea, sometimes by a great lake and then by the Sea again. The rivers from the Alps brought down boulders, gravel, and sand, gradually filling up the hollow, depositing the largest boulders at the foot of the mountains and carrying the finer materials further into the plain. The water escaped first perhaps by the Danube; there is some reason to believe that at one time it flowed by the valley of the Doubs to the Mediterranean, and lastly through Germany northwards, carrying the finer materials to build up the plains of Belgium and Holland.

Then came a period of cold—the Glacial period—when rivers of ice gradually descended from the mountains, filled up the valleys, and eventually covered the whole of the lower country with a great sheet of ice.

The Mollasse consists of beds of sandstone, marl, and, especially as we approach the Alps, of a coarse gravel known as "Nagelflue," which is often cemented so as to form a hard conglomerate. The pebbles are often crushed, sometimes compressed, and the sandstone often shows ripple marks, like those of our present sea-shores.

Seams of coal occur throughout the Mollasse; they are, however, not of any considerable extent, nor of good quality, and are generally very thin, not exceeding two feet, and rarely more than a few inches.

The character of the Mollasse in fact differs greatly in different localities, which no doubt indicates varying conditions of deposit, rather than difference of age. The beds are more compact towards the south and become looser in texture, more sandy and marly, as they approach the Jura.

Fossils are rare in the Lower Freshwater Mollasse. Still there are some places in which they occur. The Nagelflue is almost without fossils.

In the Marine Mollasse several hundred species have been determined, mostly marine shells. Remains of land animals occur, however, in the freshwater beds, including a Mastodon, two species of Rhinoceros, the Dinotherium, etc.

The Upper Freshwater Mollasse is much richer, and contains the celebrated locality of Oeningen, near the Lake of Constance, where, in strata evidently deposited in a shallow and quiet lake, have been found the remains, beautifully preserved, of no less than 1000 species of insects, about 400 plants, and many vertebrates.

At the close of the Mollasse period the great Swiss plain must have been nearly horizontal, but its elevation above the Sea was probably not entirely uniform, and some inequalities were thus produced.

The present hills, however, are mainly due to unequal erosion ; the hard Nagelflue especially has been able to resist the destructive action of time and weather.

Towards the south boundary the Mollasse is thrown into two well-marked arches, separated by a synclinal line, marked blue on the Swiss geological map.

The anticlinal line runs south-westwards from Bavaria to the valley of the Rhine, a little south of Bregenz, on the Lake of Constance, then to the Lake of Zürich, passing along the Obersee to Üznach, then across the Lake of Zug at Oberwyl, so to Lucerne, bends sharply south near Schangnau, crosses the Aar near Kirchdorf, by Guggisberg on the Sense to Lausanne, and finally in a more accentuated form gives rise to the Mont Salève (Fig. 78), south of Geneva, where the arch is broken and the Jurassic and Cretaceous strata become visible. This great anticlinal has a length of not less than 370 km.[1] At its southern limit the Nagelflue appears, though this is not yet absolutely

[1] Favre, *Rech. Géol.*, vol. i.

proved, to be in some places turned over on itself, so that we should in this case have a repetition of the conditions of the Jura (see p. 247); nearly horizontal strata to the north, then a series of folds, becoming more and more accentuated to the south, and finally turned over at the south edge.

To this, however, I shall refer again in the next chapter, and will here only observe that it would account for the enormous thickness of the Nagelflue at the Rigi; and also for the want of conformity between the strata, where the Nagelflue and Cretaceous strata meet, as, for instance, at the Vitznauerstock on the Lake of Lucerne.

The rivers are now mostly cutting into the old river terraces, and deepening their beds.

The elevation of the Alps, as already mentioned, commenced during the Eocene period, but was much more active during the Miocene.

The last period of compression and folding was later than the Miocene period, for we find the whole series of sedimentary strata from the Verrucano to the Miocene folded together.

Between the Alps on the south, the Jura and the Black Forest on the north, the great plain of Switzerland was under water and received the material brought down by torrents from the rising mountains. These deposits, forming the Nagelflue, consist of coarse agglomerates and gravels.

The pebbles of the Nagelflue are often more or less flattened, and such pebbles are frequently arranged somewhat like the tiles of a roof, so as best to stand the current. They therefore indicate the direction of the streams, showing them in general to have run from S.E. to N.W. They are larger near the Alps, as for instance at the Rigi and the Napf; and get gradually smaller to the north. Exceptions may no doubt be found, and along the Rhine the gravels contain some large blocks and pebbles of Jurassic limestone. These, however, belong to the Black Forest, and have come from the north.

Dr. Früh[1] has made a careful examination of the pebbles forming the Nagelflue. Many come from the neighbouring Flysch. Of many the origin cannot be determined. Pebbles, for instance, from the Flysch and the Lias are in many cases indistinguishable, unless indeed they contain fossils. These are unfortunately very rare. Neither Rütimeyer nor Früh, in spite of most careful search, have found any fossils in the great mass of Nagelflue forming the Rigi.

Heim, however, has met with fragments of Triassic corals, and in other districts frag-

[1] *Neue Denkschriften*, 1890.

ments of Belemnites, and such pebbles cannot belong to the Tertiary period, Belemnites being then already extinct.

It is remarkable that many of the pebbles of the Nagelflue seem to be exotic, that is to say, they do not belong to rocks found in the neighbouring mountains. We find scarcely any blocks or pebbles of the Granite, Gneiss, and Crystalline schists which now form the central mountain range of the Alps. Amphibolite, Serpentine, Verrucano, and other rocks which we should have expected to find, seem to be entirely absent. At that time, however, these crystalline rocks were covered to a great depth by the sedimentary strata. Some of the pebbles indeed do not agree with any rock now found in or near the Alps. It has, however, been suggested that some of these may really have been derived from the Alpine rocks, but before the enormous pressure had brought them into their present condition. The Nagelflue is evidently a gravel formation—an enormous cone deposited at the northern edge of the Oligocene and Miocene Alps.

The sources of certain pebbles can, however, be ascertained with great probability, and Früh concludes that the rivers came from the S. and S.E. The watershed was then further south than it is at present, and he believes that the rivers drained not only the nearer Alpine districts, but the Voralberg, the Grisons, North Tyrol to beyond Botzen, the Val Tellina, and the north of Italy, even to the Lake of Lugano and of Maggiore. The Middle Rhine, Reuss, Inn, etc., extended considerably further south. Several of the smaller streams, such as the Carassina, belonging to the Val Blegno, the Forno and Albigno and upper waters of the Maira, which now run into the Val Bregaglia to Lombardy, still show by their direction and their terraces that they originally belonged to the river system of Switzerland.

"The pebbles of the Nagelflue," says Bonney, "indicate that this river, instead of flowing as the Reuss now does for the greater part of its course over crystalline rocks, was then engaged in removing the overlying sedimentaries, and had only here and there cut down the Granitoid Gneisses and Schists.[1]

Glacial Deposits

Over the Tertiary strata lie vast masses of glacial deposits which increase in thickness as we approach the Jura, and cover the whole district with the exception of a few of the highest parts, as for instance the district of the Napf.

[1] *The Growth and Sculpture of the Alps*, Tyndall Lectures, 1888.

These deposits can be traced from their extreme limits at Lyons, high up on the Jura, and along the Aar, right up to the modern glaciers. Moreover, the characteristic rocks retain the same relative position. Many of the rocks and stones which it brought down are found in different localities, but some are confined to special districts. Guyot[1] specially mentions the Puddingstones from the Dents de Morcles, the white Granite of the Upper Valais and the Galenstock, the Euphotides of the Saas Valley, the Arkesines of the Allelin Glacier and the Val d'Herens, and the Protogine of the Mont Blanc range. These do not mix, but occupy the same relative positions at the end of the ancient glacier: the Puddingstones of the Dents de Morcles at Guggisberg; the Upper Valais rocks between Schwarzenberg and Köniz (near Bern); the Euphotides at Bern and Bourgdorf; the Arkesines at Seeberg; and the Mont Blanc Protogine at Aarwangen.

I have already indicated the borders of the great glacial sheet (*ante*, p. 129), and referred to the reasons long ago brought forward by Morlot for believing that the Glacial period was not one of continuous cold, but that it was interrupted by more genial periods.

Fig. 82 represents a section across the valley of the Aar, from Leuggern to Klingnau, a short distance above Coblenz. It is a general

[1] *Bull. Soc. Sc. Nat. Neufchatel*, vol. i.

character of the Upper terraces to be capped by loam or "Loess," the deposit of ancient floods before the present river valleys had been cut down to their present depths.

Most of the river valleys originated before the Glacial period, but the main erosion seems to have taken place between the first and second Ice ages. That they were occupied by glaciers during the second and third Glacial periods (see Map, p. 108) is proved, as already mentioned, by the existence of numerous terminal moraines crossing the valleys, and

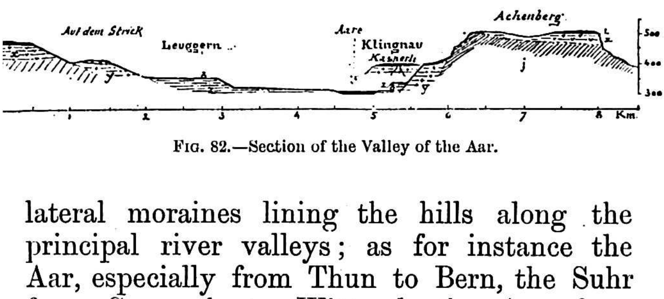


FIG. 82.—Section of the Valley of the Aar.

lateral moraines lining the hills along the principal river valleys; as for instance the Aar, especially from Thun to Bern, the Suhr from Sempach to Wittwyl, the Aar from the Baldegger See to Lenzburg, the Reuss from Klein Dietwil below Lucerne to Mellingen, the Valley of the Limmat from Rapperschwyl, on the Lake of Zürich, to near Baden.

Besides the actual moraines and the erratic blocks, the glaciers as they retreated, and the floods arising from the melting of the ice, left great masses of so-called "Diluvial" gravels, which occupy much of the valley bottoms, not having even yet been completely re-excavated by the rivers, and as we approach the Jura even form the hills, the valleys being occupied by comparatively recent river deposits. Thus the river Lorze runs on this gravel from the Lake of Zug as far as Baar: at Lucerne the gravel has been pierced to a depth of 30 metres without reaching the bottom; in several places it attains a thickness of even 60 metres.[1] The river Langeten near Roggwyl sinks almost entirely into the gravel, so that it disappears except in very wet weather, rising again in several strong springs a little further down the valley. The surface of the gravel beds is very irregular, and often gives rise to small lakes, as for instance the Mauensee, Bibersee, Finster See, Rothsee, etc. Several of the present peat mosses were formerly shallow lakes of this character. The Baldegger See and Hallwyler See are separated from one another by this Quaternary gravel, which indeed has so much raised the bed of the whole valley of the Aa, that the bottom of the Baldegger See is at the same level as Lenzburg many miles down the valley.[2]

Round the Lake of Geneva, especially on the south side, but also elsewhere, as for

[1] Kaufmann, *Beitr. z. Geol. K. d. Schw.*, L. xi.
[2] *Ibid.*

instance round Aubonne, the glacial deposits attain a great thickness. The ravines, though deep, are excavated altogether in them, and rarely penetrate to the Mollasse. They are moreover very impenetrable, as shown by the great detour which they compel the Versoix to make on its way to the lake.

To these glacial deposits the lowlands of Switzerland owe much of their great fertility.

Kaufmann [1] and Gremaud [2] attribute much importance to these deposits in determining the present courses of the rivers. They point out that while some comparatively large streams, such as the Sihl, run in narrow valleys, others, such as the Suhr, occupy much wider ones, out of all proportion to the water supply, and the size of which they account for by glacial action, especially as these wider valleys occupy just the courses of the ancient glaciers.

For instance, the Rohnthal runs almost from the lower end of the Lake of Sempach westwards to Scholz on the River Wigger. This broad valley is drained by a little stream, the Rohn, and instead of narrowing upwards, retains almost its full width. A little to the north again is the valley of the Hurnbach, which presents very similar characteristics. Kaufmann explains these

[1] *Beitr. z. Geol. K. d. Schw.*, L. xi.

[2] "Études sur les vallées de Fribourg," *Bull. Soc. Sc. Nat.*, 1888.

features by suggesting that the glacier which came down the valley of the Suhr was obstructed by the hill of Wohlen below the Lake of Sempach, and broken up; one branch passing down the present valley of the Suhr, another down that of the Rohn, while a portion of the ice surmounted the hill and continued in a direct course down the valley of the Hurnbach. The pressure of the ice caused by this obstacle may possibly account for the depression now occupied by the Lake of Sempach. The valley of the Bienz, to the west of the Reuss, which is out of all proportion to the size of the present stream, was perhaps occupied by the Reuss in ancient times. The valley contains several moraines, especially at Othmarsingen, where evidently for a considerable time was the head of the glacier, and below which the valley alters its character, becoming much narrower.

Another "dead" valley leads from the Aar at Wildegg, below Aarau, to Mellingen in the valley of the Reuss. It probably marks the ancient bed of the Aar before that river had acquired its present course through the Jura north of Lenzburg.

Gremaud has subsequently called attention to other similar cases.

The Kleine Emmen rises north of Interlaken and has a well-preserved old valley across the plateau to the Aar at Aarburg, but has now abandoned its old course at Wiggern, and turns sharply round to the east, following a trough which carries it to the Reuss below Lucerne.

The river system round Bern is also curious and interesting. From the direction of the upper Sense the natural course of the river would be by Wangen to Bern, and along the valley of the Urtenenbach to the Aar Valley below Soleure. In fact there is here a broad valley, apparently once the bed of a considerable river. At present, however, it is occupied by three streams. In the upper part, by the Sense itself, which, however, near Thörisch turns at a right angle to the east and falls into the Sarine. Below Thörisch is a small brook which falls into the Aar near Bern, and turning at a right angle also joins the Sarine. Lastly, the lower part of the valley is occupied by the Urtenenbach which joins the Emmen and falls into the Aar below Soleure.

It is clear indeed that there are many dead valleys which have once been occupied by rivers, but which are now dry; such as the Klettgau between Schaffhausen and Basle, which was probably once the course of the Rhine, or perhaps of the Aar; the Glatthal, between the Upper Lake of Zürich and the Rhine at Kaiserstuhl, which was probably one of the beds of the Limmat; the valley from

Oerlikon, by Katzensee to Wettingen, which was also once occupied by the Limmat. In some cases the rivers have been forced to change their courses by the enormous masses of glacial deposits. Thus the Sihl was probably cut off from the Lake of Zürich, and compelled to adopt its present course parallel to the lake, between the Albis range and the great lateral Moraine which forms the low ridge of hills along the west side of the lake. The Aar again appears to have been excluded from its old course down the Gauthal by the moraine at Soleure, and driven to excavate a new bed in the Mollasse.[1]

It is interesting that these deserted valleys not only contain thick deposits of river gravel, etc., but also show the usual terraces along their sides.

The remarkable case of the Venoge has been already described (*ante*, p. 193).

The Aar at Aarberg and Schinznach, the Reuss at Mülligen, and the Limmat at Baden, have sawn their way through Jurassic ridges. The Sarine cuts through several mountain ranges.[2] If these had risen more rapidly than the rivers could cut through them, they must have formed lakes, and it is even possible that for a time such lakes may have existed.

[1] Du Pasquier, *Beitr. z. Geol. K. d. Schw.*, L. xxxi.

[2] Musy, "Disc. pron. à l'ouv. de la 74e sess.," *Ann. Soc. Helv.* Fribourg, 1891.

It is clear then that the courses of the ancient rivers were in many cases very different from those of the present day.

But although on the whole the trend of the rivers is simple and uniform, there are not a few cases, as for instance in the north of the Canton of Vaud, and south of Fribourg, where the courses of the rivers are far from easy to understand. Gilliéron points out that the character of the Flysch which forms the district makes it difficult to distinguish the structure of the mountains, and that it is impossible at present to form any idea as to the original relief.

The arrangement, both of the Marine and Freshwater Mollasse, makes it probable that the drainage of Switzerland was then eastwards by the Valley of the Danube to the Black Sea. The openings which now carry the waters of the Valais westwards to the Valley of the Saône and so to the Mediterranean, and of the Aar and the Rhine by Brugg and Basle to the North Sea, were not yet in existence. The Tertiary strata of France and Germany have no connection with those of Switzerland, and were evidently separated by dry land—by the Jurassic chains. The subsidence which has given rise to the Rhine Valley from Basle northwards, and the erosion of the Rhone Valley at Bellegarde, are therefore long posterior to the period of the Mollasse.

The Rhone was eventually shut off at Mormont, between the Lakes of Geneva and Neuchâtel, the Aar at Baden, while the subsidence between the Vosges and the Black Forest opened a way for the Rhine to the north. The rivers then adopted their present courses, the Rhone to the Mediterranean, the Aar and the Rhine to the North Sea, thus depriving the Danube of a very large part of its original territory. It is evident that these changes must have taken a long time, though from a geological point of view they are very recent. The evidence of many changes in the course of the Rhine from Eglisau to Coblenz indicates this, as well as the fact that neither the Rhone, the Rhine, nor the Aar have yet been able to regularise their beds. They are divided by ridges into distinct sections with different inclinations.

The result of the general inclination of the plain is that the Lower Aar runs at the foot of the Jura, and that a succession of rivers, the Upper Aar, Emmen, Suhr, Aa, Reuss, Limmat, Glatt, Toss, and Thur, at approximately equal intervals, run from S.E. to N.W. into the Aar and the Rhine.

But while it is clear that the rivers formerly ran at a much higher level than the present, and have excavated their valleys, the great deposits of river gravel, etc., show that the valleys were at one time even deeper than they are now, and were subsequently filled up to a certain height. The present period is again one of erosion. The rivers are at present deepening their beds, but in the lower portions of their course have seldom cut down to their former level, though they have done so in some places, as, for instance, the Limmat below Baden; but in other cases where they appear to have done so, for instance the Aar at Brugg, and the Rhine near Irchel, Kaiserstuhl, Laufenberg, and Rheinfelden, though the present bed is cut into the rock, this is due to a change in the course of the river. The old river gravels at the Brugg railway station, and south of Laufenberg, are much deeper than the present river.

CHAPTER XIII

THE OUTER-ALPS

THE outer chain of the Northern Alps consists of Eocene and Secondary strata thrown into a series of folds, and running from S.W. to N.E. They extend far into Austria on the east, forming the north part of the Voralberg, and into Savoy on the west, but so far as Switzerland itself is concerned they commence in the valley of the Rhine at the east end of the Lake of Constance, form the Sentis Mountains, and the Churfirsten over the Walensee, extend by Einsiedeln and Schwyz to the Lake of Lucerne, stretch away to the Lake of Thun, and then form a grand curve with its convexity northwards, reaching almost to Fribourg, and so to Vevey and Montreux on the Lake of Geneva, to the south of which they extend into the Chablais and Savoy.

They form a complicated network, which on an ordinary map shows no regular arrangement; the configuration of the surface has been greatly affected by folds, fractures, faults, and denudation, and the structure is in many places still an enigma.[1]

They are as a rule more folded and contorted than the Jura, but less so than the central chains. The arches, however, though less compressed, are more often fractured at the summit,[2] pointing to a difference of conditions. Possibly the explanation may be that the compression was more rapid or nearer to the surface.

The Eocene strata often lie in troughs between Jurassic and Cretaceous mountains, and it has been supposed by some geologists that they were deposited in bays or fiords. It seems, however, now to be established that the Eocene strata were formerly continuous, that the elevation of the Jurassic and Cretaceous mountain ranges is of more recent date, and that where the Eocene strata are absent this is due to denudation. The presence of fragments of Eocene, as for instance on the summit of the Ganterisch near Bovatez, between the Jaun and the Montelon (though too small to be marked on the map), seems conclusive on this point.

In many places the Secondary strata have been considerably reduced in thickness by the tremendous pressure to which they were subjected during the process of folding. This

[1] Schardt, "Struct. Géol. des Prealpes," *Bib. Univ.*, Genève 1892.

[2] Favre and Schardt, *Beitr. z. Geol. K. d. Schw.*, L. xxii.

is the case for instance on the north-west of the Mattstock in the Sentis, where (Fig. 83), the Urgonian (U) is reduced from its normal thickness of 220 metres to 30 metres, or to $\frac{1}{7}$th, the Gault from 70 metres to 10, and the Seewerkalk from 100 to 12, or to $\frac{1}{8}$th. On the northern limb of the Gulmen Arch the Seewerkalk is reduced to $\frac{1}{100}$th of its original thickness, while elsewhere the strata form mere

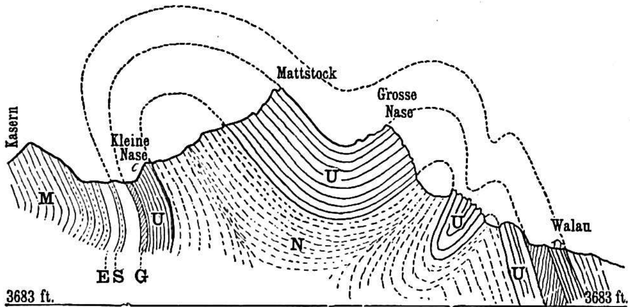


FIG. 83.—Section through the Mattstock.

shreds or detached lens-like masses, and finally in some cases disappear altogether.[1]

SENTIS MOUNTAINS AND THE LAKE OF WALENSTADT

The Sentis group and the Churfirsten occupy the triangle between the Lake of Walen and the Rhine. They are formed mainly of Cretaceous strata with a mantle of Tertiaries at their feet.

[1] Burckhardt, *Beitr. z. Geol. K. d. Schw.*, L. xxxii.

The Sentis Mountains occupy the northern and wider part. They trend from N.E. to S.W. The N.E. end consists of six ridges, due to as many folds, the ridges being often Urgonian: they gradually coalesce a little north of Wesen into two, the Goggeyenberg (with the Hädernberg), and the Mattstock (Fig. 83), and finally to one in the Küpfenstock. The ridges are generally anticlinal, but the highest summit is at the place where two synclinals meet one another. In the Churfirsten, which overlook the Lake of Walen, the strata (Fig. 26) are folded into a complete S. The configuration of the surface has been less affected by denudation in the Sentis than in most other Alpine districts.[1]

From the Sentis Mountains a glacier formerly streamed to the N.W., occupying the country between the Sitter and the Thur. The Walensee is a long valley originally due to a trough-like depression, the strata being actually folded back on themselves. The Strahlegg is a ridge of Urgonian.

The Rigi

The Rigi (Figs. 84, 85, and 88), as already mentioned, is the southern slope of a great arch of Miocene Puddingstone, the summit

[1] Heim, *Mech. d. Geb.* vol. ii. See however Rothpletz, *Geotektonische Probleme.*

and most of the north slope having disappeared. It is a gigantic bed of gravel brought from the mountains to the south.

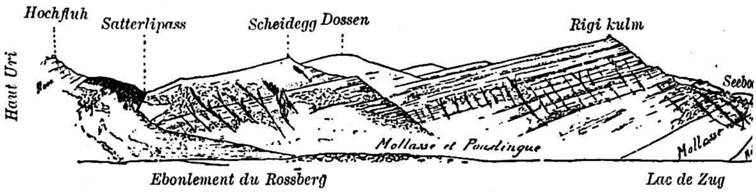


FIG. 84.—Section across the Rigi seen from the North, and showing the Rockfall of the Rossberg.

The thickness of these gravel beds at the Rigi (some 5000 feet) is enormous, and they appear to have been folded back upon them-

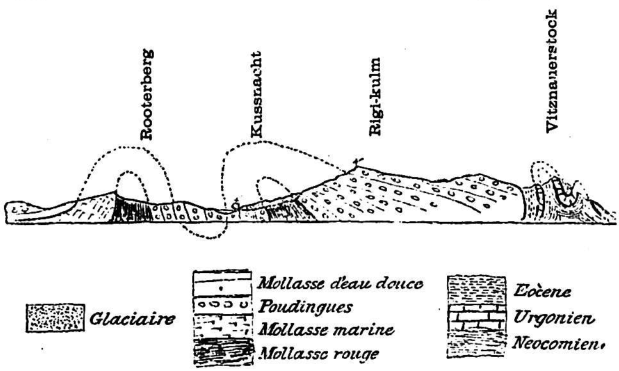


FIG. 85.—Section from the Rooterberg across the Rigi to the Vitznauerstock.

selves, though the evidence is not as yet conclusive. The mountain forms a long ridge. At the east end the Mollasse beds abut against Eocene and Cretaceous strata, which form the

Hohfluh. The Rossberg is a continuation of the Rigi. From this mountain came the great rockfall of 1806 (chap. xxii). The railway passes over the rockfall, and enormous blocks may still be seen.

It is indeed a wonderful geological lesson to stand on the summit of the Rigi and use the eyes and the brain. The view is magnificent. We see seven lakes, those of Lucerne, Zug, Lowerz, Egeri, Baldegger, Hallwyl, and Sempach. To the north is the rich plain of Switzerland, and we can trace several rivers running nearly parallel with one another to the Aar; to the west is the grand mass of Pilatus, of great geological interest, and fascinating from its mediæval traditions; to the east the Rossberg, still showing the scar of the great catastrophe of 1806, and the two mysterious Mythen; to the south, range after range of mountains, culminating in the giants of the Bernese Oberland. Greatly as these latter appear to differ in height when we are near to them, as we look from such a point of vantage as the Rigi, we see that in reality the level is very uniform, the differences and the valleys being mainly due to denudation. Under our feet is a gigantic gravel bed stretching completely down to the Lake.

Now, what are the lessons which this gravel teaches us?

1. It is obviously a gravel of mountain torrents, but which has come a considerable distance, for it is well rounded, and contains blocks up to 1 or even 2 feet in diameter.

Well-rounded gravel implies transport for a considerable distance. Bonney[1] mentions that the gravel of the Stura after a course of 32 km. was still subangular, and in the Sesia after 65 km. still only moderately rounded.

2. The character of the pebbles proves that it has come from the south.

3. This is also shown by the position of the pebbles, the flatter ones being arranged, as in modern streams, so as to offer most resistance to the current; and the position in this case shows that the stream came from the south.

4. The deposition of the gravel must have taken a prodigious time. Not only do the beds extend from the summit right down to the lake, but, as shown in Fig. 84, they slope from the Kulm to the Scheidegg. Those on the summit of the Kulm do not therefore correspond to those on the summit of the Scheidegg, but so to say to those 500 feet below. It is obvious that the Scheidegg layers were once continued over the Kulm, and even if we assume that they represent the real uppermost layers (and it is certain that there must have been others which have been removed), we must add say

[1] *Geol. Mag.* 1888.

500 feet, to the present height of the Kulm. This being 4500 feet above the level of the lake, by adding these 500, we get a thickness of no less than 5000 feet of gravel!

5. Gravel cannot be deposited on the top of a mountain. It must be formed by running water, either on a coast or in rivers—in the present case by rivers—and must therefore have been deposited at a relatively low level. As the rivers originally ran from the mountains to the S.E., the slope of the gravel must have been towards the N.W., whereas it is now towards the S.E., so that the gravel beds must have been tilted so as to dip in a direction the reverse of their original slope. That they do so slope we see clearly both from the lake and as we ascend. If, moreover, we examine the cliffs overlooking the plain we shall find that, as shown in the figure, the layers of gravel dip in towards the hill in the direction of the Scheidegg. They were in fact originally continued so as to form a great arch, the summit of which was (Fig. 85) approximately over the Bay of Küssnacht, and the north-west side immediately on the other side of the bay, where the strata are nearly horizontal, rising however almost immediately into another arch, which forms the Rooterberg. We must therefore allow for another long period, during which the summit and north-west limit of the arch were destroyed and removed.

6. The actual pebbles themselves have been carefully studied by Dr. Früh, whose Memoir has been referred to in the previous chapter, and I will here only refer briefly to three points.

1. If the central mountain ranges had been as they now are, much of the gravel must have been derived from the Jurassic and Crystalline rocks, but these are comparatively scarce, no doubt because at the time the gravel was being carried down the central rocks now exposed were covered by thick beds of the younger Secondary strata which have now disappeared.

2. Some of the pebbles are fragments of rocks now only found on the Italian side of the central ridge. They cannot of course have been brought over such a ridge, and they prove therefore that the watershed was once considerably to the south of its present line. We shall find other evidence in corroboration of this interesting fact.

3. Others of the pebbles differ from any rock now found *in situ*. It has been suggested that this is because since their removal the parent rocks have been so compressed and contorted that their character and structure have been materially altered.

The features presented along the line of contact, between the Miocene and Eocene, present much difficulty, and have given rise to various hypotheses. The strata are generally conformable, but this is by no means always the case; for instance the Miocene strata of the Rigi abut against the steeply inclined Eocene

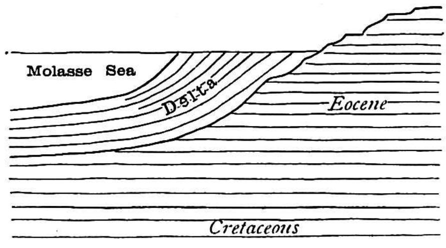


FIG. 86.—Diagram showing North shore of Alps in Miocene Times.

and Cretaceous beds of the Vitznauerstock (Fig. 85). These cases have been accounted for by supposing certain districts to have

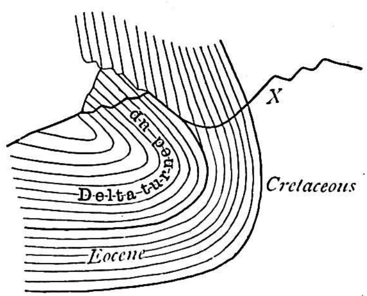


FIG. 87.—After elevation of Alps.

sunk, and great overthrusts to have taken place.

Burckhardt explains the general concordance, and occasional cases of discordance, by supposing that in the latter the Miocene strata were deposited in deltas. For instance, Fig. 86 is a diagram representing a deposit of Miocene strata in a delta. Now suppose a fold to take place, we should have the arrangement shown in Fig. 87. If then subsequently denudation took place to the dark line X, the comparatively soft Eocene strata suffering most, we should have a section not unlike that of the Rigi and the Vitznauerstock.

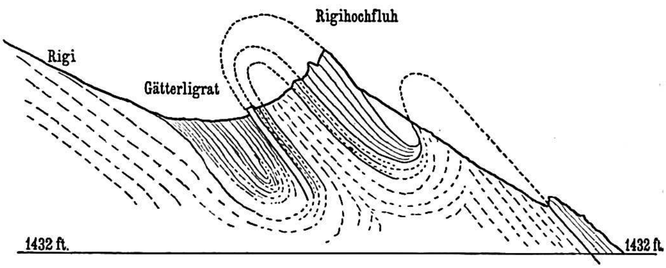


FIG. 88.—Section of the Rigi and Rigihochflue.

MOUNT PILATUS

Mount Pilatus consists of Urgonian, Neocomian, Cretaceous, and Eocene strata strongly folded. The ridges are mainly formed of Urgonian. Kaufmann[1] describes five successive folds at the north extremity, which is the summit. Towards the south-west these folds are reduced to three. It well

[1] *Beit. z. Geol. K. d. Schw.*, L. v.

deserves its ancient name of *Mons fractus*—the broken mountain.

From Staad, at the extremity of the Lake

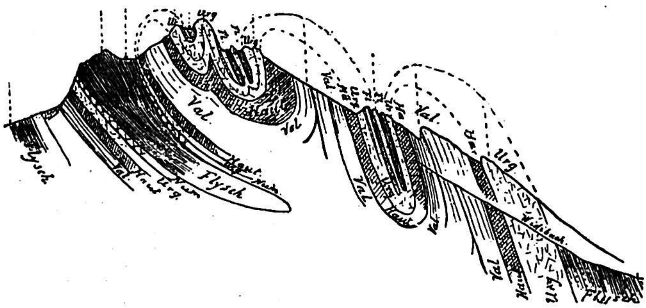


Fig. 89.—Section through Mount Pilatus.

of Alpnach, the railway rises with a very steep gradient on the south-east flank of the mountain. It crosses obliquely first the

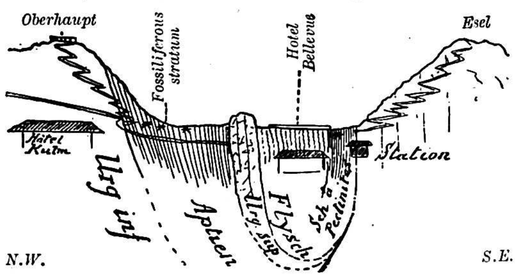


Fig. 90.—Section of the synclinal on the Pilatus near the Hotel Bellevue.

Eocene, then Urgonian, as far as the torrent of Wolfurt, where it crosses the first Neocomian anticlinal. It then enters the Eocene synclinal of Matt, touches the calcareous summit of Esel, and terminates on the precipitous slope of Urgonian.

The two hotels (Bellevue and Pilatus Kulm) are situated at the extremity of the Eocene synclinal, ensconced between the two banks of Urgonian which form the principal summits of the mountain — the Esel and Oberhaupt.

Behind the hotels, a zigzag path crosses the ridge of Urgonian by the Kriesiloch, and traversing the folded Neocomian strata descends to the Klimsen Hotel, which is situated in another Eocene synclinal. The two principal ridges of the mountain, those of the Tomlishorn and Matthorn, are formed of Schrattenkalk (Urgonian), while the valley which separates them is an Eocene synclinal — a continuation of that in which the Hotel Bellevue stands.

Glärnisch Double Fold

In some cases the strata have been pushed for considerable distances one over the other— a fact which might seem incredible, but of which we have well-established instances in the Scotch highlands and elsewhere.

One of the most wonderful cases occurs in the mountains between the Linththal and the Rhine. The strata have been compressed in a great double fold, as is shown in Fig. 91.

This double fold seemed so incredible that Studer, by whom it was first observed, hesitated to publish it. The subsequent researches of Heim seem, however, to place it beyond a doubt. Fig. 91 is a section from the Walensee, showing the remarkable folds of the Churfirsten, to the Rhine valley at Waldhaus Flims.

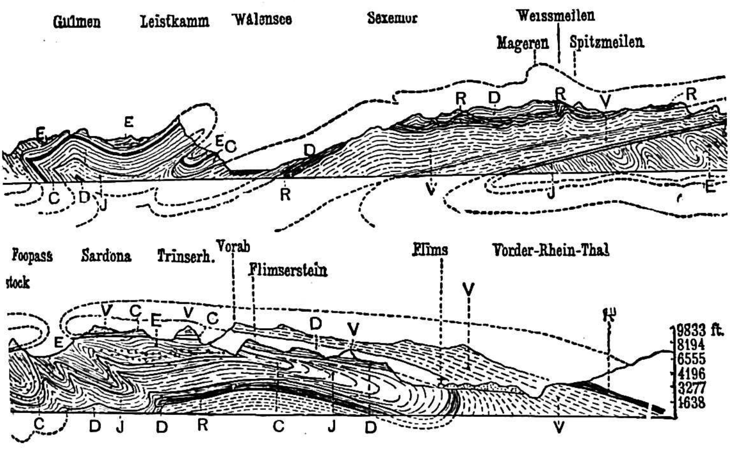


FIG. 91.—Section from the Walensee to the Rhine at Flims. M, Miocene; E, Eocene; C, Cretaceous; J, Jurassic; D, Dogger; R, Rauchwacke; V, Verrucano.

The manner in which the double fold dies away towards the east has not yet been clearly explained.

The Glärnisch and the Silbern also present a stupendous example of inversion, the strata being folded back upon themselves, so that we have Nummulitic limestone at the base, followed by Jurassic and Cretaceous strata.

I ought however to say that Rothpletz[1] has propounded another explanation, based on faults and overthrusts, which however also involves tremendous changes.

Klippen

I have reserved to the last the consideration of certain mountains, for instance the Mythen, Stanzerhorn, Buochserhorn, and others, known as "Klippen," which present problems of great difficulty.

It has been already mentioned (*ante*, p. 285) that the Nagelflue gravels consist in part of pebbles of unknown origin.

The blocks of granite known as Habkern Granite, because they exist by thousands in the Habkern valley on the Lake of Thun, belong to a variety which does not occur anywhere in the Alps. Prof. Heim suggests that they perhaps represent some of the Alpine Granite before it was crushed and folded during the elevation of the Alps.

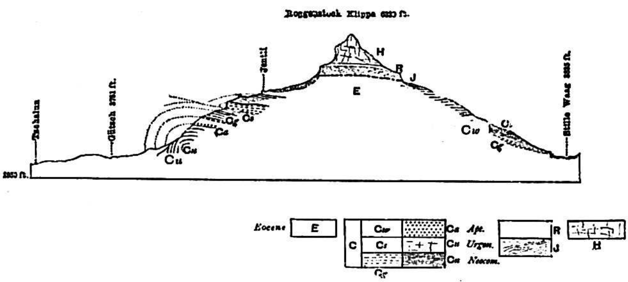
The blocks are sometimes of great size; the Berglittenstein on the Grabserberg, for instance, has a length of 40 feet.[2] Another is 105 feet long by 90 broad and 45 feet

[1] *Geotectonische Probleme.*

[2] Quereau, *Beitr. z. Geol. K. d. Schw.*, L. xxxiii.

above ground.[1] In some cases they attain the dimensions of small hills, so that we have in fact every gradation of size from a mere pebble to such a mountain as the Stanzerhorn.

Fig. 92 represents a section of the Roggenstock, and it will be seen that the more ancient Triassic and Jurassic rocks rest on the more recent Eocene beds, below which



Cw, *Wangschichten*; Cs, *Chalk*; H, *Hauptdolomite*; J, *Jurassic*; R, *Raibler Mergel*.

FIG. 92.—Section through part of the Roggenstock.

again are Cretaceous strata in regular arrangement, and with regular normal folds.

The strata in the "Klippen" slope in the most different directions; they are sometimes in the normal order; sometimes, as for instance in the case of the Roggenstock, reversed, the younger ones overlying the older; the different kind of rocks are mixed together in the utmost confusion, they are

[1] Murchison, "Structure of the Alps," *Q. J. Geol. Soc.*, 1848.

fractured, crushed, contorted in the most extraordinary manner, penetrated by veins, crossed by innumerable surfaces of sliding, and in fact have evidently been subjected to the most extreme violence, while the Cretaceous and Eocene rocks below lie comparatively undisturbed.

The "Klippen" form most conspicuous features in the landscape. To use Kaufmann's graphic expression they are "eckig, höckerig, rissig und rauh," and rise in abrupt pyramids with steep, sharp points in striking contrast with the rounded grassy slopes of the Eocene and Cretaceous layers by which they are surrounded and on which they rest.

Four theories have been suggested to account for these remarkable mountains. First, that they were pushed up by subterranean forces through the more recent beds; second, that they were islands in the Sea and that the more recent beds were deposited round them; thirdly, that they are part of an inclined fold, of which the upper part has been removed by denudation; and fourthly, that they are the remnants of great overthrusts.

It seems clear that the first supposition is untenable. The "Klippen" have no "roots." They rest upon the more recent strata. The Schien group to the N.E. of Schwyz is cut to the base by a stream, so that it takes the form of a U, and the result is to expose the Flysch, and show that the other rocks actually rest upon it.[1]

Moreover, the more recent strata show little evidence of disturbances; they present no traces of the fracture and crumpling which they must have undergone if the "Klippen" had been forced up through them.

The second suggestion, namely, that they were Islands in the Eocene and Cretaceous seas, is also untenable. The Eocene and Cretaceous strata surrounding the "Klippen" were evidently deposited at a distance from land. They do not contain the remains of a littoral fauna; and if the "Klippen" had stood up in the form of lofty islands, many pebbles from them must have been deposited in the surrounding waters.

Nor do the Klippen appear to be the mere remnants of an overlying fold. It would be somewhat difficult to condense the strong geological evidence brought forward by Quereau against this theory. I may however mention one reason, namely that the rocks of the "Klippen" present a very different facies from those of the same age in the immediate neighbourhood; for instance, the Neocomian of the Roggenstock differs greatly from the Neocomian of the surrounding district. The basis of the "Klippen," moreover, where they rest

[1] Quereau, *Beitr. z. Geol. K. d. Schw.*, L. xxxiii.

upon the Eocene, is a breccia, indicating that the upper strata have been pushed bodily over the lower.

We find ourselves then driven to the conclusion that these mountains have been literally pushed into their present position; that they are the last remnants of a range which has disappeared, and which perhaps supplied many of the enigmatic pebbles of the Nagelflue. The range was once continuous or nearly so, the fragments remaining, though now towering over the surrounding plains, owe their preservation to having been originally in a deep trough. The "Klippen" attain still greater importance to the west, where they form the mountain groups of the Stockhorn and the Chablais.

Haug[1] and Lugeon have suggested that they have been forced to their positions from the Briançonnais, before the elevation of the intervening mountains: that the whole of the Pre-Alps from the Arve to the Lake of Thun in fact is a vast zone of overthrusts from the other side of the range of Mont Blanc.

No doubt the strata present very much the same aspect as those of the Briançonnais, and were evidently continuous; but while

[1] Haug, *L'Origine des Pre-Alpes Romandes.*

the existence of an overthrust seems to be demonstrated, further evidence is still required as to the locality from which they were brought.

Other great cases of overthrust extending for several miles have, as Quereau points out, been established in Scotland, in Provence, in the Appalachians, and as we have already seen, by Heim in Glarus.

Moreover, however improbable, not to say impossible, this explanation may at first sight appear, we must remember the enormous disturbances of which we have the clearest proof. As already mentioned it has been calculated that the strata which lie between Basle and Milan, a distance of 130 miles, would, when extended, have occupied 200 miles.

The origin of the "Klippen" is still, however, a matter of discussion, and in the most recent memoirs on the subject, M. Ch. Sarasin,[1] and M. Schardt,[2] differ in several respects from the conclusions of M. Quereau.

[1] *Arch. de Genève*, 1894.

[2] Schardt, "Struct. Géol. des Pre-alpes," *Bib. Univ.*, Genève, 1892.

CHAPTER XIV

CENTRAL MASSIVES

THE Alps are not, strictly speaking, a chain of mountains, but rather a series of bosses, or "central massives," to use the term of the Swiss geologists.

Speaking generally, we may say that the Central Massives have Gneiss as the central rock with Crystalline schists, of uncertain age, on the sides; followed by other rocks undoubtedly of sedimentary origin, but so much metamorphosed that it is in many cases difficult, or even as yet impossible, to determine their geological position.

The Central Massives were at first regarded as grand, but simple arches, and this impression is still widely diffused, partly because in the small generalised sections which alone can be given in text-books, it is impossible to give details.

Their structure is much more complex than would be inferred even from the largest geological maps. In Studer's excellent map, for instance, the whole of the St. Gotthard route from Erstfeld to Lugano is colored as Gneiss, with the exception of three belts—that of Protogine from Wasen to Goschenen; of the Secondary strata which constitute the Urserenthal, and another Secondary belt forming the Bedrettothal, and crossing the Ticino at Airolo to the Val Piora. The great Swiss Dufour map shows that the structure is far from being so simple; but in fact no map can adequately show its real complexity. The following figure (Fig. 93) gives a faint idea of the complexity of the St. Gotthard Massif. The whole tendency of recent researches has been to demonstrate that the structure of these "central massives" is much more complicated than had been at first supposed—to confirm Saussure's wise saying that "Es giebt in den Alpen nichts Constantes als die Mannigfaltigkeit."

In this respect, however, the massives differ considerably. Monte Rosa, for instance, is simpler than the St. Gotthard. Indeed, the southern Gneisses are, as a general rule, much less contorted than those in the northern massives.

The strata form more or less lenticular masses, and are very varied in composition and structure — the Gneiss itself presenting many varieties.

The Gneiss, Granite, Protogine, and even apparently Mica Schist pass almost imperceptibly into one another. "The changes of texture and condition," says Escher, "vary not only in different layers, but even in different parts of the same layer, so that we often pass from one extreme to the other by imperceptible gradations."

Grubenmann,[1] who has recently published a special memoir on the Granites of the St. Gotthard, suggests that they may all have been derived from an originally similar rock, modified by differences of pressure and temperature. Schmidt suggests that we find normal Granites in just those parts of the central massives where we should expect the pressure to be less extreme, while Protogine occurs in the more intensely folded parts.

Heim has pointed out that many rocks which in hand specimens might well be taken for Granite are shown to be really stratified if seen in larger masses. As already mentioned, he regards some varieties of Gneiss as part of the original Earth's crust. He regards parts of the Protogine as compressed Granite, and some of the Gneiss as compressed Protogine; while other Gneiss masses he regards as metamorphosed sedimentary rocks, and he refers to places where the one passes imperceptibly into the other.

Duparc and Mrazec,[2] who have especially

[1] *Verh. Thurgaisch. Nat. Ges.* 1890.
[2] *Arch. Sc. Phys. et Nat. de Genève*, 1892.

studied the Protogine of the Mont Blanc Massif, regard it as a granulitic Granite, "présentant une disposition en bancs plus ou moins épais, acquise à la suite d'actions dynamiques ultérieures à sa consolidation."

On a larger scale the sections show repeated successions of similar rocks, and the more they are examined the more complicated do they appear.

In the Aar profile we find Granite repeated at least nine times, Gneiss-Granite ten times. Eyed-gneiss, Mica Gneiss, and Gray Gneiss several times. In the Reuss Valley the Granite and Crystalline schists alternate some twenty times in a distance of 4 km. The Urseren fold is itself double. These changes may in some cases be due to faults and overthrusts, but in general appear to indicate folds. Baltzer considers that the Aar massif comprises at least six.[1]

The following figure (Fig. 93) representing the section of the St. Gotthard Tunnel, shows this complexity very clearly.

The existence of "bosses," such as the great "massives," would naturally follow from the general view of the Swiss Alps, which has been given above. It would be most improbable in any case, that we should have a simple succession of ridges extending the whole length of the mountains, and especially so in a

[1] Baltzer, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.

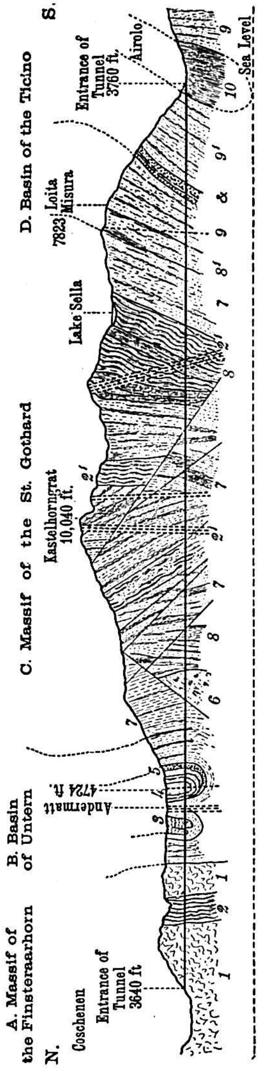


FIG. 93.—Section of Mount St. Gotthard on the line of the Railway Tunnel. 3¼ miles. 1, Granite; 2, Gneiss with veins of Mica and Eurite; 2¹, Gneiss with quartzose and green beds; 3, Lipoline; 4, Sericite schists; 5, Black schists; 6, Serpentine; 7, Gneiss passing into quartzose and mica schists; 8, Hornblendic rocks; 8¹, Hornblendic rocks; 9, Felspathic, calcareous, and Garnetiferous Mica schists; 9¹ Quartzose schists; 10, Dolomites.

curved chain, such as the Alps. Moreover, we find as a matter of fact, that folds rarely extend the whole length of a range. In the Jura, for instance, which extends over 300 km., the folds have lengths of 12, 27, 28, 31, 45, 14, 51, 92, 48, and in one case 162 km. respectively. The length, I may add, has no relation to the height. Thurmann calculated that for the whole Jura there are no less than 160 folds, though there are never more than 12 in any one cross section.

As a rule the strata on the northern line of the Central Massives are inclined at a high angle, and indeed are in places perpendicular. This may be said to be the rule in the centre, while they are less steeply inclined at the sides. The inclination, however, instead of being, as might at first sight have been expected, away from the centre, trend towards it. Indeed, so extreme has been the pressure that the central ranges have been squeezed into a fan-shaped structure, long ago noticed by Saussure, well described by Studer, but first explained by Lory. Fig. 25 gives a section across the Mont Blanc range.

A similar fan-shaped structure occurs in the St. Gotthard (Fig. 26), the Grimsel, the Silvretta, etc., and may indeed be said to occur in all the northern Crystalline Massives of the Alps, but not in the Ticino, Adula, etc. It has also been found in the Pyrenees, in Pennsylvania, and some other mountain ranges.[1]

Figs. 94 and 95, showing the folds assumed by layers of clay, sand, etc., in two of Mr. Cadell's experiments, compared with the

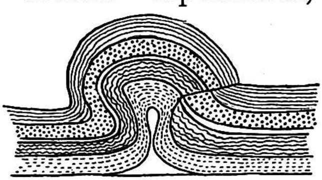


FIG. 94.

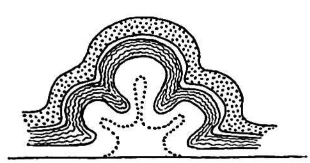


FIG. 95.

Diagrams showing the structure of Folded Mountains.

section of the Mont Blanc Massif given in Fig. 25, or that of the St. Gotthard in Fig. 26, show how the structure of these mountain ranges may have originated.

[1] Favre, *Rech. Geol.*, iii.

In attempting to understand the structure of the Central Massives, the first problem which confronts us is the true nature of the Crystalline rocks. They were long regarded as intrusive plutonic rocks, which had forced up, and were therefore younger than the Secondary strata. As already mentioned, however (*ante*, p. 32), they are now regarded as essentially passive, not active; not as having forced up the Secondary rocks, but as having been forced up with them by the same lateral pressure; as being of extreme antiquity, and indeed in the opinion of some geologists as part of the original crust of the Earth.

Some Swiss geologists consider that the Crystalline rocks had been not only denuded, but also much folded before the deposition of the Secondary strata; other great authorities, as for instance Heim, dispute this; they consider that the earlier folding was comparatively slight, and that in the main the folding of the Gneiss and the Secondary strata was simultaneous.

The Central Massives, the Mont Blanc Massif, the St. Bernhard, Monte Rosa, Aar, St. Gotthard, Adula, etc., are at present more or less completely detached.

It has long been a question whether these mountain masses should be regarded as independent centres of elevation or as parts of a general system. As long as mountain chains were regarded as having been thrust up from below by volcanic action, the former view seemed most probable.

The structure of the rocks affords no conclusive evidence. They agree no doubt in general character. The Gneiss of the Aar Massif cannot be distinguished from that of the St. Gotthard Hospice. The Protogine also repeats itself. That of the St. Gotthard Massif from Medels to Somvix is practically identical with that of Mont Blanc.

On the other hand, the fundamental rocks are very similar all over the world. Moreover, underlying this similarity there are considerable differences in detail.

These differences may be in many cases due to mechanical causes—those, for instance, between the St. Gotthard and the Adula, perhaps to the fact of the former being more compressed. It seems clear, however, that the rocks in each differ as much as those between different "massives."

Moreover, as the rocks included in the folds between the massives are of the same age, we can hardly doubt that this applies to the massives themselves. Here also the analogy of the Jura is very instructive. The bosses there are not on so grand a scale, they are not formed of such ancient rocks, and they are not so far denuded; but they are clearly parts of a system, and I cannot doubt that the same is the case with the great massives of the central Swiss chain.

The Granite is no doubt for the most part of great antiquity, pebbles of it occurring in Carboniferous Puddingstone; it crops up in many places, now more or less detached, and there were probably several distinct eruptions of this rock; but the action of subsequent denudation has divided many tracts which unquestionably were once continuous. Some Granite is no doubt intrusive. This is shown by the fact that the rocks near it are in many places forced up and modified by heat. Still it would be a mistake to regard the Granite as having been the active agent of disturbance; it was, on the contrary, itself forced up by the general side pressure. In some cases it appears not to have entirely broken through the overlying rocks, but is exposed in deep ravines.[1]

I have already shown that the Central Massives were once covered by a great thickness of Secondary rocks. Apart from this evidence, however, we must bear in mind that Gneiss, Granite, and Crystalline Schists must have cooled under great pressure and at a great depth. When we stand on such a rock we must in imagination replace over it several thousand feet of rock now removed. Gneiss would as it approached the surface gradually

[1] Theobald, *Beitr. z. Geol. K. d. Schw.*, L. iii.

have assumed a totally different character, the superficial parts probably not differing greatly from modern lavas.

These upper layers were removed by denudation, and on the surface thus exposed was deposited a great thickness of Sedimentary rock. Figs. 25 and 26 show that on both sides of the Mont Blanc Massif and that of the St. Gotthard are folds of Secondary strata; these must have been originally continuous, and have passed over the intervening mountains in a great arch.

Sorby, as already mentioned, considered that the Granites examined by him had cooled at a depth of no less than 30,000 feet.

While, then, we have still much to learn as to the structure of these Central Massives and their relation to one another, there are strong, not to say conclusive, reasons for regarding them—

(1) As an integral part of the general Alpine system, not as independent centres of upheaval; and (2) as complex systems of compressed folds.

CHAPTER XV

THE LAKE OF GENEVA

Mon Lac est le Premier.—VOLTAIRE.

THE Lake of Geneva is 45 miles in length, and about 10 in breadth. It is 375 metres above the Sea, and 309 in depth.

The bottom, moreover, is covered by subsequent deposits to an unknown depth, so that originally it was probably below, perhaps much below, the Sea level. Indeed, if the slopes of the mountains at Meillerie and Vevey (see Fig. 100) are continued under the bed of the lake, the alluvium must have a thickness of no less than 600-800 metres, which would make it 200-400 metres below the Sea level. The actual outlet at Geneva is in superficial debris, but the river comes upon solid rock at Vernier, 1197 feet above the Sea level, 33 feet therefore below the surface level of the lake, and 951 feet above the bottom. It is therefore a true rock basin.

In the Port of Geneva, a little to the

S.E. of the Jardin Anglais, are two erratic blocks which project above the water. They are known as the Pierres de Niton, and it is said that in Roman times sacrifices were offered to Neptune upon them.

The Lake of Geneva has somewhat the form of a crescent, and if we remember that the valley, as far at any rate as St. Maurice, if not to Brieg, was once part of the lake, the resemblance must have been even more marked formerly. Port Valais is supposed to have been on the lake in Roman times.

The primary rocks nowhere make their appearance round the Lake of Geneva. The east end of the lake is a transverse valley cut through a succession of synclinal and anticlinal folds in strata extending from the Triassic to the Tertiary. The rest of the lake from Clarens on the north, and Meillerie on the south, lies in Miocene (Mollasse), which, however, is in many places covered by glacial deposits. On the south especially, these attain a considerable thickness.

Most of the promontories round the lake are traversed by a stream; they are, in fact, river cones. That of Yvoire, however, cannot be so accounted for; and Favre[1] has pointed out that it is, in fact, a great moraine. It is one of the most picturesque districts of the whole shore. The view of the lake, the

[1] *Rech. Géol.*, vol. i.

magnificent groups of chestnuts, and the innumerable erratic blocks, give it quite a special character.

The plain on the south side of the lake, and even the high terrace of St. Paul, above Evian, is entirely erratic, and due to the confluence of the ancient glaciers of the Rhone and the Drance. The deposits attain an immense thickness in the valley of the Drance, above Thonon, from the study of which Morlot many years ago convinced himself of the existence of at least two glacial periods.

The chain of the Voirons is an anticlinal N.S. ridge, overthrown to the west; and the arch is more or less profoundly broken to the Flysch, the Neocomian, or even the Malm.[1]

The country about Vevey and Montreux

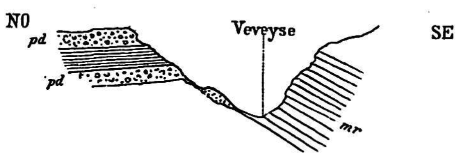


Fig. 96.—Section across the Valley of the Veveyse.

is the Riviera of Switzerland. It is lovely now, but what must it have been before the monotonous terraces of the vineyards and the endless rows of vine bushes replaced the ancient forests of Chestnut, Birch, and Beech; and the picturesque Swiss chalets

[1] Renevier, *Add. Pres. Soc. Helv. des Sc. Nat.* 1893

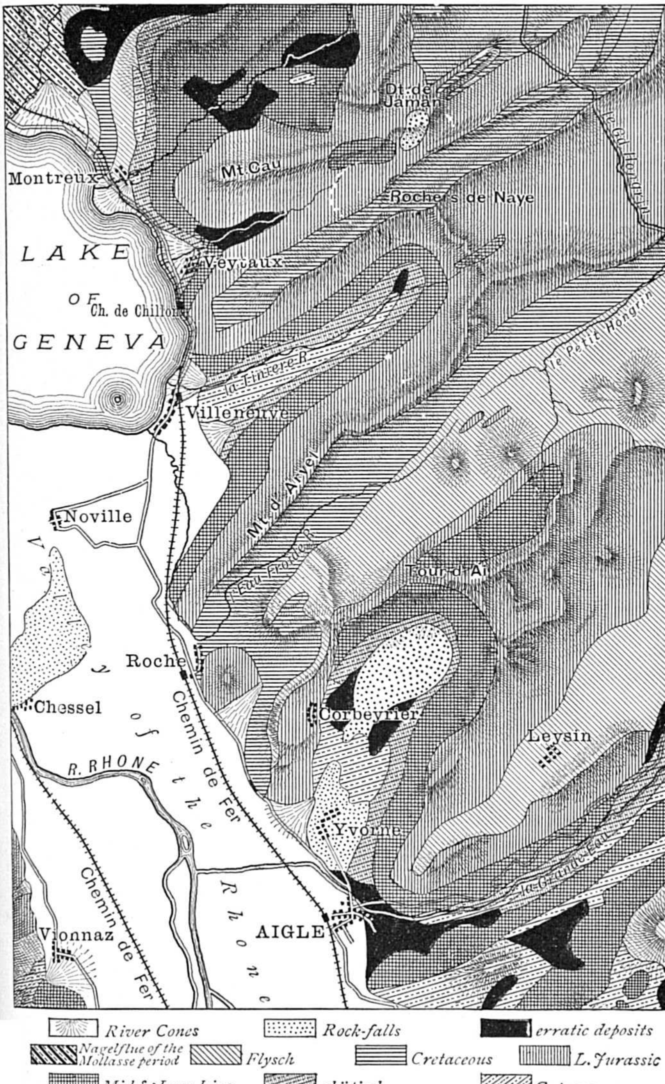


FIG. 97.—The east end of the Lake of Geneva, and part of the Rhone Valley.

were extinguished by whitewashed villas and gigantic hotels.

Morlot first called attention to the existence of a fault to the west of Vevey. It begins at Gonelles, just to the west of the town, and goes in the direction of Châtel St. Denis, following for some distance the right bank of the Veveyse.

The cone of the Tinière is particularly interesting from the attempt made by M.

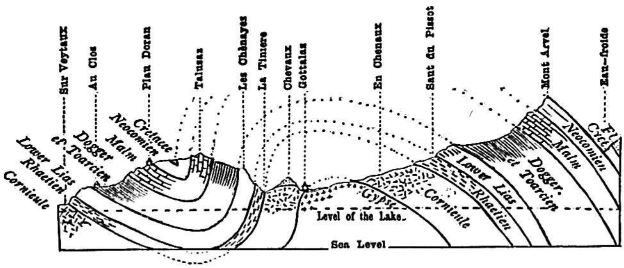


FIG. 98.—Transverse Profile of the Valley of the Tinière, near Villeneuve.

Morlot to calculate roughly the date of the later Stone·Age in Switzerland. He estimated for the age of Bronze an antiquity of from 2900 years to 4200 years, for that of the Stone period from 4700 to 7000 years, for the whole cone of from 7400 to 11,000 years.

At the eastern end of the Lake of Geneva (Fig. 97) the strata are thrown into a series of arches on the north side. Messrs. Renevier and Golliez give the following series :—

1. Anticlinal valley of the Verage at Jaman.
2. Synclinal ridge of Sonchaud at Naye.
3. Anticlinal valley of the Tinière (Fig. 98).
4. Synclinal valley of the Eau Froide (Cretaceous and Flysch).
5. Anticlinal Cirque of Corbeyrier (Triassic).
6. Synclinal plateau of Leysin.
7. Anticlinal valley of the Grande Eau, excavated down the Trias.

The Tour d'Ai which forms so conspicuous a feature in the landscape at the eastern end of the Lake of Geneva is, as shown in Fig. 99, the point of a broken arch of Malm.

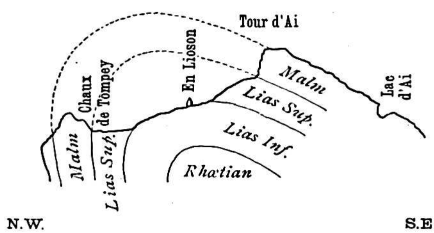


FIG. 99.—Section across the Tour d'Ai.

From the Rocher de Naye, now accessible by a mountain railway, there is a glorious view. To the east the Bernese Oberland, further west the Dent du Midi and the extreme summit of Mont Blanc, to the north the great plain of Switzerland, around us the Pleiades, etc., the Tours d'Ai and de Mayen, a wilderness of ridges and valleys, gray precipices, steep bright green grass slopes, mottled with dark masses, patches, lines, and groups of pines, below which are paler green deciduous trees, and at our feet the blue water of the Lake of Geneva.

Conformation of the Lake

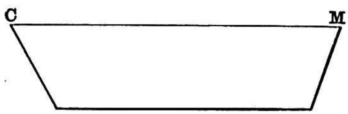
Though the form of the lake is in itself so simple, the lake is in reality formed of two converging basins: that of the east which is a cross valley, while the western half, like the Lakes of Neuchâtel, of Bienne, and of Morat, follows the direction of the Jurassic chains and the anticlinal axis of the Mollasse. The Petit Lac, the Lake of Neuchâtel, and that of Bienne may almost be said to form one lake basin. It probably originated at the same time as the mountains, which have the same general curve as that part of the lake.[1]

The eastern end, on the contrary, as far as a line crossing from Vevey to Meillerie is a transverse valley or cluse, cut through the Secondary and Eocene strata, which are thrown into a succession of synclinal and anticlinal folds. The greater part of the original "Haut Lac" is now a plain, filled up to an unknown depth by the deposits of the Rhone. The "Haut Lac" is in fact a transverse river valley cut out by the Rhone, and subsequently, owing to a change of inclination, partly filled up again.

[1] Favre, *Rech. Geol.* vol. i.

This distinction between different parts of the lake is to some extent recognised in the local nomenclature, the eastern end being known as the "Haut Lac," the centre as the "Grand Lac," and the narrower western end as the "Petit Lac."

The water of the Rhone from its greater density sinks rapidly below the blue water of the lake, but the fine mud is carried halfway across the lake, and covers the bottom as far as Amphion and St. Sulpice.



Scale: horizontal 1:200 000^e, vertical 1:25 000^e.

FIG. 100.—Profile across the Lake of Geneva from Cully to Meillerie.

The "Grand Lac" is bounded on the north by Miocene Mollasse, on the south as far as Tour-Ronde by Lias and Jurassic, and further to the west by immense alluvial and glacial deposits. The centre (Fig. 100) is occupied by an almost horizontal plane at a depth of 309 metres, indicating that the alluvium must be of great depth.

The western half of the lake is in almost horizontal strata of middle Miocene Mollasse. It was therefore excavated after the middle Miocene, and before the close of the Glacial epoch.

As already mentioned, there is some reason for supposing that the Petit Lac was originally the valley of the Arve. It presents a general inclination from Geneva to Morges, but with some slightly marked basins, owing to transverse banks, which Forel considers to be ancient moraines. The sides, moreover, like those of an ordinary river valley, slope more or less towards the centre. I have already (*ante*, p. 193) given reasons for thinking that the outflow of the waters was formerly, not at Geneva, but between Morges and Lausanne, to the Lake of Neuchâtel.

The following figure gives the profile from St. Prex to Amphion.

Scale: horizontal 1:200 000e, vertical 1:25 000e.

FIG. 101.—Profile across the Lake of Geneva from St. Prex to Amphion.

It must always be remembered that the vertical and horizontal scales in this and other similar figures are quite different. They bring out clearly the special point which they are intended to illustrate, but in other respects might give an erroneous impression. We generally think of the Lake of Geneva as deep, but taken in relation to its area it might almost be described as a film of water (see Fig. 68).

Between Yvoire and Rolle, and at a depth of 60 metres, is a remarkable bank known as the Omblière, because it is the best fishing ground for the "Omble Chevalier," which comes there to breed. It is an old moraine, and is also remarkable because a moss (Thamnium alopecurum, var. Lemani) still lives on these stones.[1]

The "blue waters of the arrowy Rhone"[2] "rush out with a depth of 15 feet," says Ruskin, "of not flowing, but flying water; not water neither, melted glacier matter, one should call it; the force of the ice is in it, and the wreathing of the clouds, the gladness of the sky, and the countenance of the time."[3]

The remains of the lake villages show that, as in the other great lakes, the surface level has varied very little for several thousand years; for if the water level had been lower, the remains would have been destroyed, and on the other hand the piles could not have been fixed in deeper water.

At present the lake is maintained at a nearly constant level by dams and sluices at Geneva.

The condition and configuration of the Lake of Geneva offer many difficult problems, as to which there is still much difference of opinion.

The course of the Rhone below the Lake of Geneva is extremely curious and interesting. It presents many indications of

[1] Forel, *Le Léman*. [2] Byron. [3] Ruskin.

comparatively recent origin, or at any rate of recent changes.[1] At the Fort de l'Ecluse it passes through a narrow cañon or gorge, several hundred feet in depth, between the Credo (Cret d'Eau) and the Vuache Mountain (Fig. 77). The gorge coincides with a change in the direction of the mountain chain which has, according to Bourdon, given rise to a fault, the difference of level between the Credo and the Vuache amounting to 1000 metres. It then enters a plain, and at Bellegarde joins the Valserine, which though the smaller is really the mother river. Immediately above the junction is the celebrated Perte du Rhone, where the river narrows to about 15 metres,[2] and when it is low disappears more or less completely for 20 km. running in a deep, narrow, winding, and often invisible bed.

This is due to the presence of horizontal layers, differing considerably in hardness. Fig. 102 represents a longitudinal, and Fig. 103 a transverse, section—*a*, *a* are hard Calcareous strata, *b*, *b* softer layers. The boulders with which the river is laden, by degrees broke through the harder rock in various places, and then began to act more effectively on the softer stratum below, which they gradually ate into more and more, finally meeting, and

[1] "Le Canon du Rhone," *Bull. Soc. Géol.*, France 1894; Schardt, "Chaine de Reculet Vuache," *Eclog. Géol. Helv.*, 1891.

[2] Lenthéric, *Le Rhone*, vol. i.

thus forming a sort of tunnel sufficient to carry all the water of the river when it is low. The lower Calcareous layer has in some places been itself worn through, so that the same process is beginning a second time. Neither the Rhone nor the Arve would by itself have been able to effect this. It requires gravel and boulders, animated by a sufficient force of water. The Rhone is large enough, but does not carry down enough stones. The

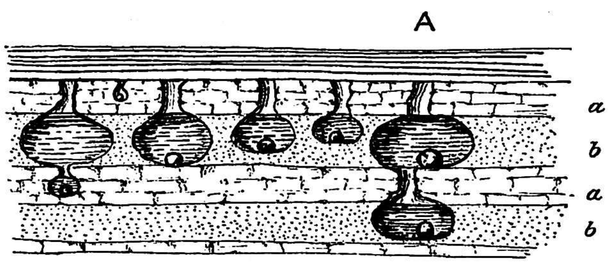


FIG. 102.—Longitudinal Section of the Perte du Rhone.

Arve has plenty of gravel and stones, but not enough flow of water. Thus the Rhone supplies the force and the Arve the tools.

From the Fort de l'Ecluse to below Malpertuis the Rhone is not a river, but a torrent. It has not had time to approach its "regimen."

Below Bellegarde the slope of the river is the reverse of that of the valley. The river slopes from Bellegarde to Malpertuis, the valley from Malpertuis to Bellegarde. The river falls 20 to 25 metres, the ground rises over 200. At Bellegarde the gorge has a depth of 200 metres, at Malpertuis of 450.

Thus while the river falls the valley rises. If this had always been so it is evident that the Valserine and the Rhone would have formed a deep lake, the bottom of which they would have filled with river deposits, and round which we should find traces of lake terraces. Of such a lake, however, there is not a trace.

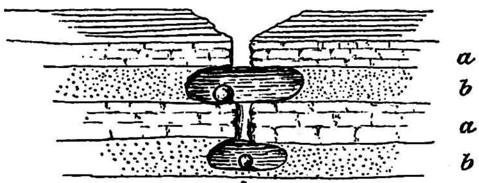


FIG. 103.—Transverse Section of the Perte du Rhone.

Near Malpertuis the inclination of the ground changes, slowly at first, afterwards more rapidly. The slope of the valley coincides with that of the stream, and at Seyssel the Rhone is a river again. The relation of the drainage to the surface is therefore very remarkable.

We are driven then irresistibly to the conclusion that the high ridge between the Perte and Seyssel is of comparatively recent origin; that it has risen since the Rhone ran in its present channel, and that it was cut through by the river as it rose.

M. Bourdon is disposed to think that it

is actually still rising. He points out that the present heights in many cases differ from those marked on the Government map, but it is very possible that they may have been right when the measurements were made, and have since altered.

There has been a law-suit going on for nearly two centuries between the Canton of Vaud and that of Geneva, the former alleging that the mills, dams, etc., at Geneva have raised the level of the lake, flooding some of their roads and fields. The evidence they have produced seems conclusively to show a slight elevation of the level of the water. On the other hand, the people of Geneva appear to have proved that there has been no such change of level there. It seems possible that both may be right and that Geneva is even now slowly rising. Time will solve this interesting problem.

On the whole it seems probable that the two ends of the Lake of Geneva represent the river valleys of the Rhone and the Arve respectively; that they met the Dranse opposite Morges, and that the combined river ran north to the Lake of Neuchâtel; that an elevation of the land then dammed back the water, giving rise to the lake; and lastly, that the cutting of the gorge at Fort de l'Ecluse gave the lake its present exit to the west, and gradually lowered the level.

CHAPTER XVI

THE MASSIF OF MONT BLANC

Il y a dans la nature comme dans les arts des choses difficiles à comprendre, qu'on doit voir ou entendre plusieurs fois pour en saisir la grandeur; il en est ainsi de la chaîne du Mont Blanc, plus on la voit et la parcourt, mieux on en saisit la beauté. FAVRE.

THE Massif of Mont Blanc is elliptical in outline, about 30 miles in length, and 10 in breadth, extending from S.W. to N.E. from the Col de Bonhomme, across the Valais at Martigny to the Dents de Morcles, the extreme N.E. portion being severed from the rest by the Rhone.

It consists mainly of two unequal ranges (see Fig. 104), the lesser, that of the Aiguilles Rouges on the N.W. and the greater Mont Blanc range on the S.E., separated by the longitudinal valley of Chamouni, and bounded by two others, the Vallée de Sixt on the north, and the Val Ferret on the south. These valleys have been greatly deepened by erosion, but are clearly due in the first instance to geotectonic action. Thus the Val Ferret extends from the Allée Blanche on the west to Sembranchier on the east, but with higher portions at the Allée Blanche and the Col de Ferret, so that the waters meet one another almost half-way between the two at the foot of the Glacier de la Brenva, when they turn south through a transverse valley to Villeneuve, S.W. of Aosta between Mont Chetif and the Mer de la Saxe, which seem to guard the entrance, as Studer says, like the pillars at the entrance of an Indian temple.

The central range and the summit of Mont Blanc itself (4810 metres) consists mainly of Protogine, flanked as we pass to the north by Crystalline Schists of undetermined age, succeeded by strata belonging to the Carboniferous, Jurassic, and Cretaceous periods.

The Grands Mulets and the Dome du Gouté consist of Crystalline Schist, which indeed surrounds the whole massif, except on the south side, where it is wanting in the Val Veni, the Val d'Entrèves, and the Val Ferret. In this respect the north and south sides of the chain present a remarkable contrast.

Figs. 94 and 95, adapted from Mr. Cadell's experiments on the foldings of compressed layers of clay, illustrate the structure of the Central Massives; that on the right giving the "fan" structure, while that on the left shows an overthrust, and suggests a possible

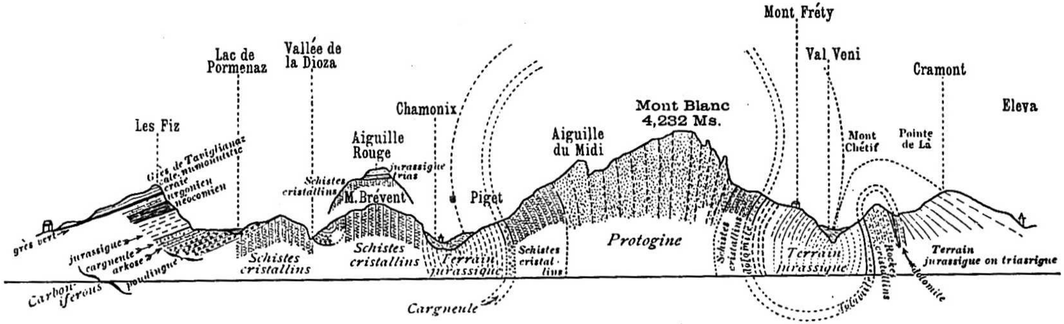


FIG. 104.—Section across the Mont Blanc range.

explanation for the absence of the Crystalline Schists on the south of the Mont Blanc range.

Carboniferous strata occur on both sides of the Arve, from Servoz almost to Les Houches, and extend eastwards in two bands —one from Servoz towards Mont Buet, the other from below Argentière over the Col des Montets down the Trient to Vernayaz, and across the Rhone to the Mont de Fully. The broad valleys of Chables and of Liddes are also due to the comparative destructibility of the Anthracitic shales belonging to this period.

The three principal representatives of the Carboniferous strata are (1) argillaceous schists, frequently containing vegetable remains; (2) micaceous sandstones, which often much resemble some of the Crystalline Schists; and (3) the remarkable conglomerate known as the Puddingstone of Valorsine.

This Puddingstone consists of rolled pebbles and blocks, sometimes over a foot in diameter. These must have been brought down by torrents much resembling the Alpine torrents of the present day, and indicate therefore the presence of former mountains.

The pebbles consist principally of primitive rock, mainly Gneiss, but comprise no Granite or Porphyry, so that these rocks cannot then have been exposed, but must have been covered and protected by other strata. The pebbles are mixed with Quartz and Mica embedded in a hard reddish cement. Blocks of this Puddingstone, as already mentioned, have been transported by the glacier to a great distance.

It was well studied and described by De Saussure in 1776 at Ceblancs, on the north of the mountain Les Posettes, where the layers are vertical, while, as De Saussure remarked, they must have been horizontal, or nearly so, when originally deposited. "Il faut donc regarder," he says, "comme une chose demontrée, que ces poudinges ont été formés dans une position horizontale, ou à peu près telle, et redressés ensuite après leur endurcissement." This important observation was the first proof of the elevation of Sedimentary strata.[1]

However self-evident this may appear to us now, it seemed extraordinary at the time, and Bertrand even attempted to show that the pebble beds might have been deposited in a vertical position!

The proportion of pebbles in this deposit varies greatly. Sometimes they form nearly the whole, with only enough cement to hold them together. At other places they are comparatively few, or even altogether absent, in which case it is very difficult to distinguish this rock from one of the Crystalline Schists.

Favre indeed suggests that some of the rocks which have been regarded as Crystalline Schists in reality belong to the Carboniferous period.

[1] Favre, *Rech. Geol.*, vol. ii.

The Val Ferret and the valley of Chamouni are synclinals, and contain Jurassic strata.

As regards Mont Blanc itself, "Je n'entreprendrai pas," he says, "de décrire l'apparence du Mont Blanc, on ne peut se faire une juste idée de cette chaîne couverte de frimats éternels et ornée de mille pointes de rochers, sans l'avoir visitée. Il y a dans la nature, comme dans les arts, des choses difficiles à comprendre, qu'on doit voir ou entendre plusieurs fois pour en saisir la grandeur; il en est ainsi de la chaîne du Mont Blanc, plus on la voit et la parcourt, mieux on en saisit la beauté."[1] The whole district is of singular beauty. "I have climbed much," says Ruskin, "and wandered much, in the heart of the high Alps, but I have never yet seen anything which equalled the view from the Montanvert."

Favre also speaks of this district with great, though not too great, enthusiasm, as "des lieux enchantés," and returned over and over again to the Pavillon de Bellevue during his geological studies. He does not know which to commend most, the splendid air or the magnificent views, which, as he justly says, surpass all description.

The true continuation of the valley of Chamouni eastwards is not the Col des Montets and the Tête Noir, but the Col

[1] Favre, *Rech. Geol.*, vol. ii.

de Balme. The Arve descends in a longitudinal valley to Les Houches. Here the western line of the valley passes over the Col de Voza. The river, however, breaks away to the north in a transverse valley, cutting across the Carboniferous strata. The contrast of the narrow and wild transverse gorge, with the more open longitudinal valley above, is very marked. Below Servoz for a short distance the river again occupies a longitudinal valley, and then from Sallenches runs transversely by the narrow gorge at Cluses to Bonneville, where it emerges on a wide alluvial plain.

As already mentioned, the Val Ferret on the south, and the mountains on the west, which stretch from the Rhone valley, south of St. Maurice, to the valley of the Arve at Servoz—the Mont Ruan, the Cheval Blanc, and the Mont Buet, are Jurassic: and the question arises whether the Secondary strata once extended in a great arch over the Protogine of Mont Blanc. This can now be confidently answered in the affirmative, and the final proof is due to M. Favre. On a memorable occasion, 12th August 1847, he ascended the Aiguille de Glière. It was a splendid day, and he says,[1] "Je fis une longue station au sommet de cette aiguille, jouissant de divers points de vue. Je con-

[1] Favre, *Rech. Geol.*, vol. ii.

siderais longtemps avec un inexprimable plaisir cette scène majestueuse, mais tout à coup je remarquai, au Nord-Est, dans l'une des Aiguilles Rouges, une structure qui me ramena subitement à un autre ordre d'idées, non moins grand et non moins relevé que la rêverie où m'avait plongé la contemplation du grand spectacle que j'avais sous les yieux.

"Je voyait toutes les Aiguilles Rouges formées de gneiss en couches verticales; je les examinais avec la lunette, lorsque je fus frappé de l'espèce de chapeau que portait la plus élevée. Ce chapeau (Figs. 104, 105) est formée par des couches presque horizontales, reposant sur les tranches du gneiss qui composent le corps de la montagne. Cette vue captive toute mon attention. Il était évident que la discordance que je voyait entre les couches presque horizontales et le gneiss indiquait que le chapeau de l'Aiguille Rouge était d'une autre nature que l'aiguille même."

The "cap" was in fact formed of Jurassic strata, conclusively demonstrating that the Secondary rocks once extended continuously over the massif; and, to judge from their thickness elsewhere, the amount of the Secondary rocks denuded can hardly be less than 3000 metres, to which a substantial addition must be made, as a considerable thickness of the crystalline rocks has also been removed.

Whether the same can be said of the older

Tertiary strata is not so clear, but as they terminate along the north side of the Mont Blanc massif in a great escarpment, it is certain that they must at any rate have extended far beyond their present limits. South of the Alps the cretaceous and nummulitic strata reappear in the neighbourhood of Varese and Turin.

At any rate, however, the Secondary strata formed a great arch over the Buet, dipping

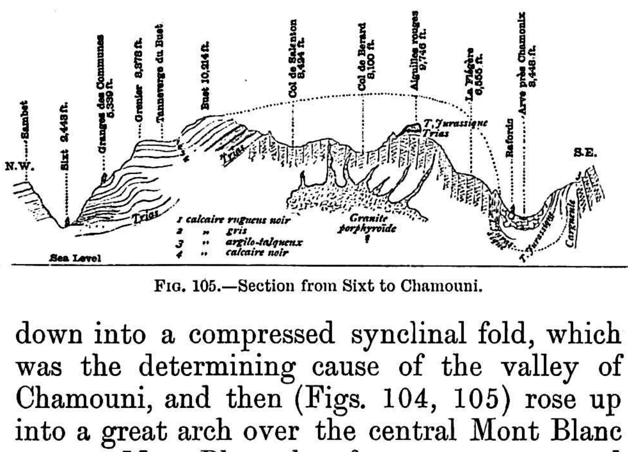


FIG. 105.—Section from Sixt to Chamouni.

down into a compressed synclinal fold, which was the determining cause of the valley of Chamouni, and then (Figs. 104, 105) rose up into a great arch over the central Mont Blanc range. Mont Blanc therefore was once covered by from 10,000 to 15,000 feet of strata, which have been entirely removed.

The lapse of time thus indicated must have been enormous. It has been calculated that the general surface of the land is lowered by the action of rain and rivers about 1 metre in 12,000 years,[1] though no doubt the rate would be greater in mountainous regions.

The valley of Chamouni presents grand evidence of glacier action. It contains numerous erratic blocks and several glaciers. That of Argentière almost closes the upper valley. It has a height of over 100 metres, and was the right lateral moraine of the Glacier d'Argentière. The right lateral moraine of the Glacier des Bois does not stop with the glacier, but is prolonged in the form of an immense rampart, which formerly extended right across the valley, damming back the river, and forming a lake. It has now, however, been cut through by the Arve, forming the Passage des Tines. It has a height of over 170 metres, and one of the largest of the blocks, known as the Pierre de Lisboli, is 15 metres in length. The Arve has raised the whole valley above this moraine.

Chamouni itself is built on, and to a great extent of, a former terminal moraine of the Glacier des Bois. This is shown by the character of the blocks, which are of Granite, very different from the rocks of the Brevent.

Lower down the valley, at Montquart, is another moraine, which ends a little below the torrent coming from the Glacier de Taconnaz. One of the blocks belonging to it, known as

[1] Penck, *Morphologie der Erdoberfläche*, vol. ii.

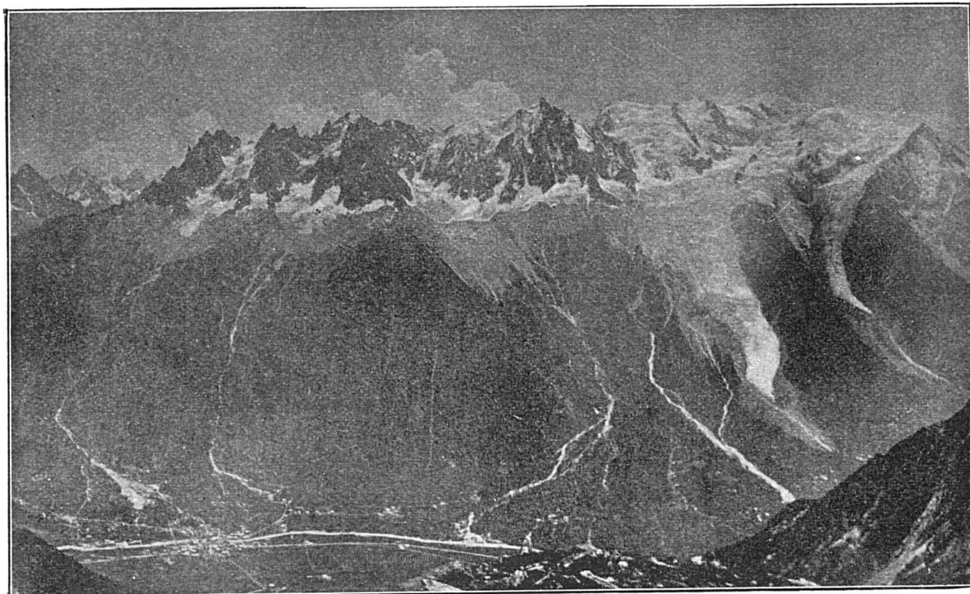


FIG. 106.—Valley of Chamouni.

the Pierre Belle is 24 metres long, 9 wide, and 12 in height.

At an earlier period, however, the whole valley was filled by the glacier, and all along the face of the Mont Blanc range the upper limit of the ice can be clearly traced (see Fig. 106). At this epoch the glacier divided, one branch passing down the Arve, the other over the Col de Balme, and the Tête Noir to the Valley of the Rhone.

These moraines are very instructive, because they connect so clearly the ancient glaciers of the Ice Age with those of the present day.

In the valley of Chamouni glacial action, as indicated by the smooth and rounded surface of rock, can be traced over the Col des Montets between Valorcine and Argentière, a height of 1474 metres, at the Chalet de Pliampra, 2080 metres, and to the summit of the Posettes, 2208 metres.

At the bend of the river Arve, opposite Les Houches, where the river turns abruptly into a transverse valley, the rocks are greatly glaciated. At Châtelard, near Servoz, at the right side of the road, are several very fine Giants' Caldrons.

Below Servoz the river again turns and enters another longitudinal valley. Further down on the right side between Combloux and Sallenches, M. Rendu long ago remarked with surprise that the cultivated ground rose to a certain height, and was then suddenly cut off by a belt of wood. This he found was due to a lateral moraine, the great blocks rendering cultivation impossible. It is one of the most remarkable groups in the Alps, and is probably due to its position just opposite the defile of Servoz, by which the great glacier descended into the valley of Sallanches. The moraine does not cease at Sallanches, but continues all down the defile of Mayland. It exists, however, on the left side only. Not a single block of Granite occurs on the right anywhere in the whole defile. Why is this?

Rendu suggested the explanation. A smaller glacier from the Buet joins that of the Arve at Servoz, and continues with it down the valley. This affluent, however, came from a calcareous region; the blocks forming its moraine, therefore, are undistinguishable from the debris which have fallen from the mountains, and are moreover more perishable than the blocks of Protogine coming from the Mont Blanc range. The whole plain between Cluses and the Salève is covered with glacial deposit, and strewn with blocks of Protogine, except a calcareous band of very variable width extending from the opening of the valley of Bornand, by St. Laurent, La Roche, and Cornier, and ending somewhat to the east of

Regnier. This is known as "Les Rocailles," is sterile and comparatively uncultivated. It is, in fact, a moraine belonging to the ancient glacier of the Bornand valley.

Fig. 104 shows the fan structure so characteristic of the Alpine massives.

The junction of the Crystalline Schists and the Protogine is well seen at Angle, on the edge of the Mer de Glace, above Montanvert. The schists become more Crystalline as we approach the Central Massif, and at the line of junction with the Protogine, can hardly be distinguished from true Gneiss. The Felspar is generally white, sometimes rose. The Mica is white, brown, or black. The celebrated "Jardin" is an island of rock in the Glacier du Talèfre.

In the centre of the Plan des Dames, on the Col du Bon Homme is a cairn, on which it is the custom for every passer-by to place a stone, as is done in Jerusalem on the so-called Tomb of Absalom, and in so many other places.

As usual in the Alps, the drop on the south side is more abrupt than that on the north, and the transverse valleys are consequently shorter. In fact, the mountains form a grand and almost continuous wall from Mont Blanc to the Aiguilles d'Argentière. There are only two or three passes, and those very lofty. The Col de Géant is that most frequently used.

Of all the views in the Alps, says Forbes, few if any can be compared with that of the Mont Blanc Massif from Courmayeur.

The moraines on the south of the chain are also very grand. The Cretaz de Saleinoz in the Val Ferret is one of the most magnificent in the whole Alps. It was the former right lateral moraine of the Glacier de Saleinoz, but is now quite detached from the glacier. It has a height of from 30 to 50 metres, and bears many immense blocks of Protogine.

The polished surfaces of rock near the Glacier de Triolet, and of Mont Dolent reach a height of 2500 metres, that is to say, nearly to the Col du Petit Ferret.

The moraine of Ivrea at the mouth of the Val of Aosta (see p. 110) is the greatest in the Alps, or indeed in Europe.

CHAPTER XVII

THE VALAIS

THE valley of the Rhone, from the Lake of Geneva to the Glacier, forms the Canton of Valais—the valley par excellence.

The present valley from Villeneuve to the Gorge of St. Maurice was evidently at one time a part of the lake, and would be so still if it were not for the deposits brought down by the Rhone.

From Villeneuve to Martigny the Rhone occupies a transverse valley, cutting across the strike of the strata, which form a succession of complicated folds, the strata being often, as it were, brayed together, and sometimes vertical. They correspond on the two sides.

The valley is, no doubt, of great antiquity. Favre and Schardt consider that it originally formed a narrow gulf of the sea.[1] This view has also the support of Renevier's high

[1] *Beitr. z. Geol. K. d. Schw.*, L. xxii.

authority, but seems to me, I confess, improbable. It has all the appearance of a river valley, but is no doubt very ancient, probably as old as the Miocene. It belonged originally to the Dranse de Bagne, and is most likely older than the upper valley or than the elevation of the Bernese range.

It is indeed difficult to account for the facts, except by assuming that the Dranse was running approximately along its present course before the folding at St. Maurice commenced, and cut back the ridge as it rose. In this case, the Dranse is probably an older river than the Rhone, and to it properly belongs the valley between Martigny and the Lake of Geneva.

Down to comparatively recent times the lower Valais was marshy, and subject to destructive floods. Hence, we find that the towns are generally placed on the cones of the lateral streams,—Aigle on that of La Grande Eau, Bex at the mouth of the Avençon, Monthey of the Viege; Muraz, Vionnaz, Vouvry, Aux Evouettes, etc., on the cones of other streams. The most remarkable cones are those (1) of the Bois Noir (Fig. 107), formed by the torrent of St Barthélemy, and above Martigny; (2) that of Chamoson at the mouth of the Losenze, which is 4 km. in length, and rises from 480 metres to 730 metres, having therefore a height of

250 metres;[1] and (3) the most striking of all, that of the Illgraben near Leuk. The amount of stones, etc., brought down by these three torrents has been so enormous as to dam back the river, and thus raise the general level of the valley for some distance above them.

The plain of the Rhone valley where the river enters the lake is almost absolutely flat, but from Noville to Chessel are a number

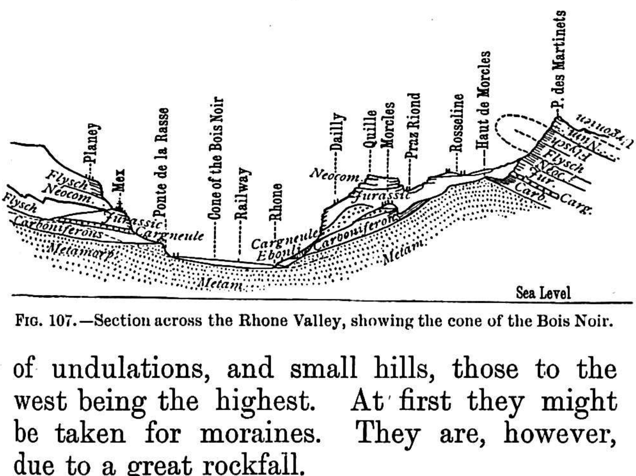


FIG. 107.—Section across the Rhone Valley, showing the cone of the Bois Noir.

of undulations, and small hills, those to the west being the highest. At first they might be taken for moraines. They are, however, due to a great rockfall.

The originally horizontal beds near Noville have been thrown into zigzags by the pressure of the fallen material. The scar, still known as the Derochiaz, is even now visible, immediately above Aux Evouettes. Morlot was in-

[1] Renevier, *Beitr. z. Geol. K. d. Schw.*, L. xvi.

clined to identify this catastrophe with the great rockfall of 456 A.D., which, according to Marius d'Avenches and Gregory of Tours, overwhelmed the town of Tauredunum. Others, however, consider the Derochiaz fall to be more ancient, and point out that the fallen materials do not reach the foot of the mountain, but are separated by a stretch of absolutely flat ground. This they account for by supposing that the valley of Derochiaz was occupied by a small glacier, which acted as a sort of bridge, and over which the debris glided into the middle of the valley.[1]

There was a great rockfall from the Dents du Midi in 1835, producing a torrent of black mud which flowed down the St. Barthélemy and covered the Bois Noir. Other rockfalls in this district have been already alluded to.

The rocky hill of St. Triphon, opposite Ollon, must have been once an island. The sides plunge down almost vertically. There can be no doubt that the usual talus or scree exists at the base, but it is covered over by the alluvium, showing that the valley was a lake down to, geologically speaking, a very recent period.

The bottom of the valley to a considerable depth consists of alluvium containing freshwater and sometimes land shells. The Navisance has cut 300 to 400 feet through gravel.

[1] Favre et Schardt, *Beitr. z. Geol. K. d. Schw.*, L. xxii.

On both sides of the Valais, marks of glacial action reach to a great height, and the upper limits of the ancient glacier can often be clearly traced. The glacial deposits in the lateral valleys are also of immense magnitude. The valley of Devens, between the Grionen and the Avançon, is especially remarkable in this respect, and contains many immense blocks.

On the left bank of the Rhone a great moraine, which has been rendered classic by the labours and descriptions of Charpentier, extends, with some intervals, from the plateau of Verossaz above St. Maurice by Monthey to Muraz. It is almost entirely composed of Protogine from the north slopes of Mont Blanc. Some of the blocks are so large that they have received special names—the Pierre à Dzo, Pierre à Muguet, etc.

At Bex are the celebrated Salt mines in the Trias which have been worked for over 200 years, and were at one time managed by Charpentier, who resided at the village of Devens.

The Dolomite and Gypsum, which are generally considered to be Triassic, are especially susceptible to the action of weather and water; hence the rivers (as, for instance, the Grand Eau), and the Cols (as, for instance, the Col de Pillon between the upper valleys of the Grande Eau and the Sarine, those of la Croix, Kinmeun, Fruttlisspass, etc.) have a tendency to follow the outcrop of these strata.

The Gypsum also often gives rise to swallow holes, sometimes of considerable size. The little lake of Plambouit, which is said to be very deep, occupies one of these depressions.[1] When the Gypsum occupies high ground, it weathers into peculiarly pointed peaks, like those of the Dolomites.

From the lake to Bex the valley is wide and open, but from St. Maurice to Martigny it is comparatively narrow, owing to the

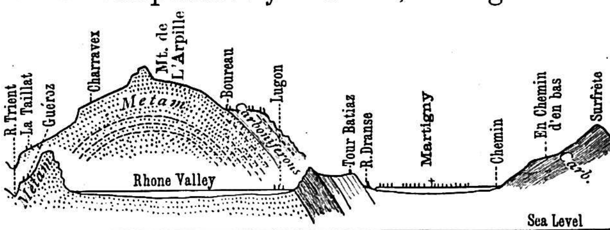


FIG. 108.—Section across the Rhone Valley at Martigny.

greater compactness of the rocks. Immediately below St. Maurice is a belt of dark, hard rock, belonging to the age of our chalk; then come Crystalline rocks—the eastern extremity of the Aiguilles Rouges Massif, with a synclinal containing Carboniferous Puddingstone, and slate, which is worked near Vernayaz.

A short distance above St. Maurice the torrent of St. Barthélemy has formed the fine cone of Bois Noir (Fig. 109), and driven the Rhone to the foot of the Dents de

[1] Renevier, *Beitr. z. Geol. K. d. Schw.*, L. xvi.

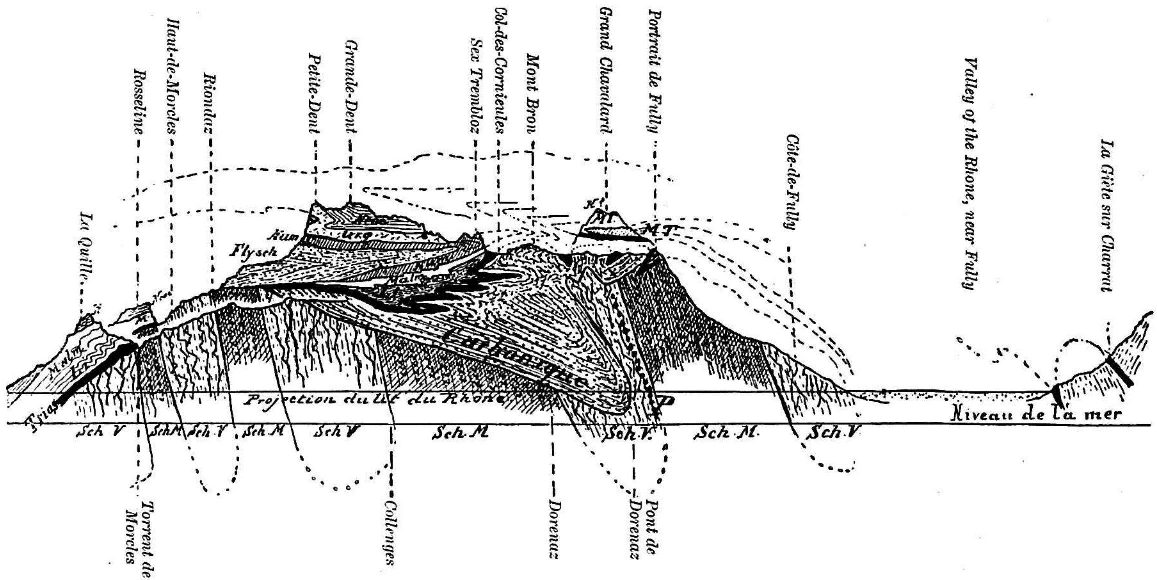


FIG. 109.—Profile of the Dents-de-Morcles. *Num*=Nummulitic; *N*=Neocomian; *Ml*=Malm; *Li*=Dogger and Lias; *MT*=Triassic Marble; *Sch. V.*=Green Schists; *Sch. M.*=Mica Schists; *P*=Ancient Puddingstone in the Green Schists.

Morcles. Fig. 108 gives a section across the valley at Martigny; it will be seen that the strata at the Pont des Martinets are reversed.

The crystalline rocks consist of Chloritic schists, alternating several times with Mica schists. Prof. Golliez regards them as archaic sedimentary rocks much metamorphosed, but their age is still uncertain. They must be very ancient, for they are folded, and in his opinion this must have occurred before the deposition of the Carboniferous strata which lie unconformably upon them. If this view be correct we have here evidence of three great periods of disturbance—firstly, that of the Chloritic schists, secondly, of the Carboniferous strata, which overlie the schists, and thirdly, the great Cretaceous Nummulitic fold which forms the summit of the Dents de Morcles.

Over St. Maurice on the west tower the magnificent Dents du Midi, which form so striking a feature in the view from the north side of the Lake of Geneva from Lausanne to Montreux, are certainly among the most beautiful of Swiss mountains.

The whole mountain has a torn and wild appearance. It is a part of the great Cretaceous Jurassic range which extends from the Lake of Walen, by Glarus, the Windgälle, across the valley of the Reuss, through Ob Dem Wald, by Grindelwald, Lauterbrunnen, the Gemmi, to the Haut de Cry and the Dents de Morcles, which are a counterpart of the Dents du Midi on the south-west. The strata, as shown in Fig. 110, are inverted; the older Neocomian resting on the younger Nummulitic, which again reposes on Flysch.

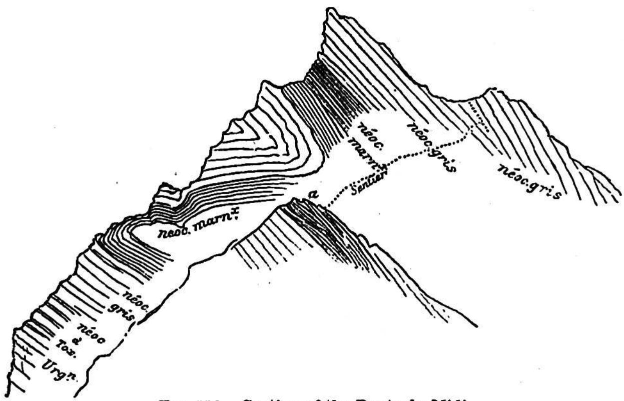


FIG. 110.—Section of the Dents du Midi.

For some distance on each side of Martigny, from Outre-Rhone nearly to Saillon, the bottom of the valley presents a number of Sand-dunes, first described by Morlot. They resemble in miniature those of the desert, and of some sea coasts. The most considerable are near Charat, and reach a height of 20 to 30 feet. They are formed especially in the spring when the Rhone is low, and leaves large sandy tracts uncovered.

Shortly below Martigny on the left side two streams enter the Rhone valley—the Sallanches and the Trient—but there is this remarkable difference, that while the Sallanches forms a beautiful waterfall, the Trient has carved for itself a deep and narrow gorge. The rocks over which they flow are similar, and apparently of equal hardness, and their difference is probably due, partly to the fact that the Trient, draining a larger area, has a more considerable water power, and also that it brings down more pebbles and boulders, while the Sallanches is a clear stream.[1] Most of the tributaries in this district enter the Valais through gorges more or less similar to that of the Trient; those of the Lizerne, the Salenze, and the Triège are the most remarkable.

The station of Vernayaz, at the opening of the gorge, which is well worth a visit, stands actually on the axis of the Carboniferous fold, and quarries of slate occur on both sides of the valley. They alternate with layers of Puddingstone. The Chloritic schists are well seen at the gorge of the Trient, which is cut through them.

From Martigny starts the great road over to St. Bernard, and Brockedon, who knew

[1] Gerlach, *Beitr. z. Geol. K. d. Schw.*, L. ix. p. ii. Favre, however, *Rech. Géol.*, vol. ii. seems to indicate that the strata through which the Trient runs, yield rather more easily to water action.

the passes well, assures us in a passage with which I entirely concur, that, besides the wildness of this Alpine pass, and the beauty of the valley of Aosta, through which the road to Turin continues after it leaves the mountains, "the kind reception which the traveller experiences from the religious community at the hospice on the summit of the St. Bernard, is remembered as long as he can be grateful for the devotion which induces these excellent men to offer to the travellers their welcome, and spread for him their hospitality in the wilderness."

At Martigny the Rhone turns at a right angle. In fact it leaves the great longitudinal fold and enters a transverse valley properly belonging to the Dranse. During the Ice Age the ancient glacier in making this sharp turn pressed with enormous force against the rock-face opposite Martigny, which is tremendously worn and polished, affording in Ruskin's opinion the most remarkable illustration of ice action to be found in the whole Alps. Above Martigny we come to the true Rhone valley—the only part of its course which really belongs to the Rhone, for the valley below Martigny originally belonged to the Dranse, that below Bellegarde to the Valserine, and below Lyons to the Saone.

The valley from Martigny to Oberwald

is a longitudinal valley of geotectonic origin, due to a fold created during the elevation of the Alps. This great fold stretches west by Chamouni and the Isère to Chambéry, eastwards by the Urserenthal and Rhine valley as far as Chur, reappearing indeed still further to the east.

At Martigny itself the strata are nearly vertical (Fig. 111). The old Tour de la Batiaz

FIG. 111.—Face of the rock from S.E. to N.W. at Martigny.

stands on a narrow band of Jurassic rock, which extends west over the Col de Balme to the valley of Chamouni, and eastwards up the valley of the Rhone. It is a continuation of the great synclinal of Chamouni.

For some distance above Martigny the valley of the Rhone was evidently once under water. M. Renevier considers that it was a distinct lake from that of Geneva, separated by the ridge at St. Maurice, but M. Forel has clearly shown that there was a time when the waters of the Lake of Geneva stood at a much higher level than the present, and they must then have been extended far up the Rhone valley. The present level of the lake is 375 metres, the Rhone valley between Monthey and Bex is 400 metres, Martigny 460, and Brieg 670. The bottom of the valley is, however, raised by the alluvial deposits, the thickness of which is not known. When,

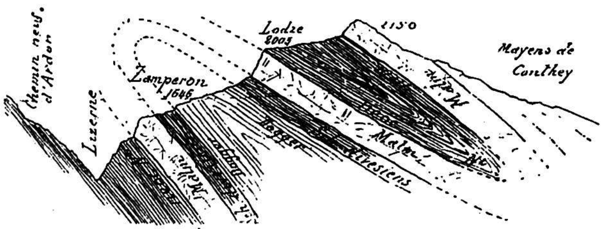


FIG. 112.—Transverse profile of the Gorge of the Lizerne.

therefore, the lake was at its highest it possibly extended to Brieg, though at another time the part above Martigny may very likely have formed a separate and upper lake. To the east of Martigny is another belt of Crystalline rocks, while some little distance up the Dranse, at Sembrancher, we come again upon Jurassic, the eastern prolongation of the Jurassic synclinal of the Val Ferret. The valleys of Liddes and Chable owe their origin to the softer Carboniferous (Anthracitic) strata.

Fig. 112 represents a section of the valley

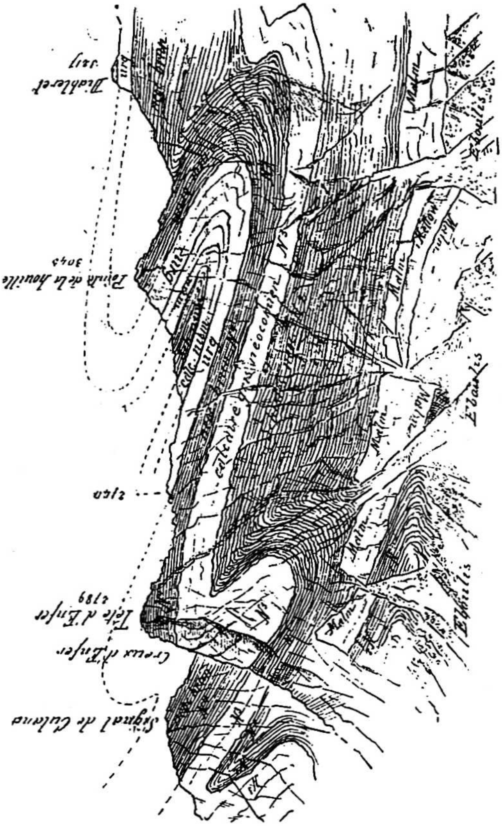


FIG. 113.—Part of the south wall of the Diablerets.

of the Lizerne, which falls into the Rhone at Ardon below Sion.

The above section (Fig. 113) shows the

remarkable contortions of the strata on the great south wall of the Diablerets seen from the Tour d'Anzeindaz. The summit here marked as Pointe de la Houille is perhaps more generally known as the Tête Ronde.

The next figure (Fig. 114) represents a section from north-north-east to south-south-west.

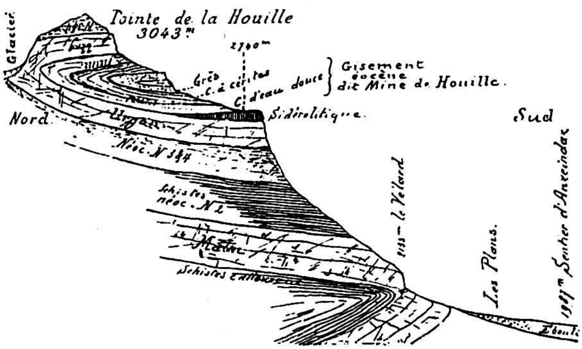


FIG. 114.—Section of the wall of the Diablerets.

This "lying fold" is a remarkable case of complete inversion.

The chain of Argentière between, but somewhat west of, the Diablerets and the Haut de Cry is formed of vertical Urgonian strata, and when seen in profile, seems sharp as a knife edge. At the Lion d'Argentière, so-called from a fancied resemblance to a couching lion, the strata are also inverted, so that the summit is formed by reversed Urgonian resting on Neocomian, Nummulitic, and Flysch.

FIG. 115.—Section of the Haut de Cry.

Nearer to, and more conspicuous from, the Valais is another great rock wall, that of the Haut de Cry. Fig. 115 shows the folds of the strata, which, if the light suits, may be clearly made out from the valley.

Above Martigny one sees clearly the contact of the Calcareous and Crystalline rocks on the north of the valley gradually descending towards Saillon. Sion owes its picturesque and feudal aspect, and indeed, its importance in mediæval times, to the fact that the river has left several masses of native rock, on which three castles were built. The highest was formerly the Bishop's Palace, built in 1492, but now a ruin. Just above Sion the Borgne has formed a fine cone, and driven the Rhone to the foot of the opposite mountain.

At and round Sierre we find the remains

of the most gigantic rockfall in the whole of Switzerland, excepting that of Flims in the valley of the Rhine. It extends from Pfyn almost to the mouth of the Liena, and has a width of about a mile. It must have long dammed up the valley, but is now completely cut through both by the Rhone and by several tributary streams. The surface is very irregular, in many places reaching a

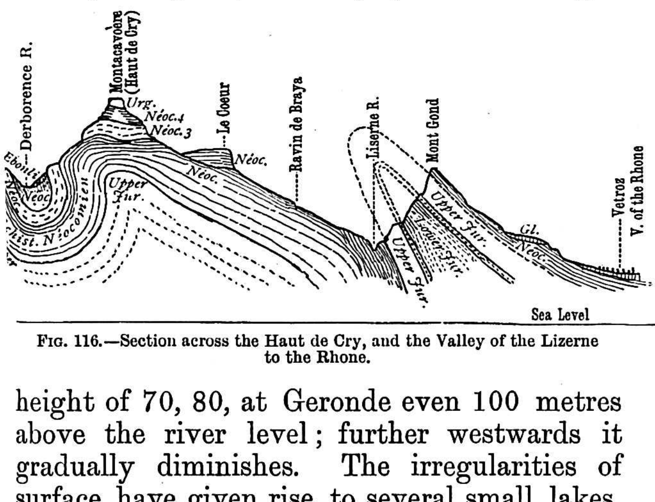


FIG. 116.—Section across the Haut de Cry, and the Valley of the Lizerne to the Rhone.

height of 70, 80, at Geronde even 100 metres above the river level; further westwards it gradually diminishes. The irregularities of surface have given rise to several small lakes, the largest of which, a little north of Geronde, is 450 metres long, 100 to 150 broad, lies 3 metres below the level of the Rhone, and has a depth of 8 to 10 metres. The banks are very steep. The landslip took place above Cordon, under the Varener Alp. It was prehistoric, but must have taken place after the retreat of the great glacier. A beautiful bronze sword was found in a grave on the hill of Tevent, below Sierre, showing that the fall was before the Bronze Age.

Opposite Leuk is the grand cone of the Ill, which has again driven the Rhone to the north side of its valley, and to some extent dammed back the river. The valley of the Ill —the Illgraben[1]—affords one of the most striking instances of recent rapid denudation with which I am acquainted, and is well worth a visit.

Between Turtmann and Raron well-marked lines may be seen on the north side of the valley. These are "Bises" or artificial watercourses, and are fringed with lines of trees. The north side, being most exposed to the sun, is comparatively dryer and more bare than the south, which is greener and well-wooded. The side of the valley above Gampel is much smoothed and rounded.

Many of the lateral valleys, for instance, on the south side those of Iserable, Nendaz, Herins, Reschy, Anniviers, Turtmann, and Ginanz, though broad in their upper parts, open into the main valley by narrow, and often, inaccessible gorges.

Similar cases also occur on the north side. The gorge of the Jollibach at Nieder

[1] Murray's Handbook, though as a rule marvellously accurate, gives the Illgraben as a case of rockfall.

Gestelen (Jolebach on some maps) is 200 to 300 metres deep, and in places only a few metres in width, cut through Calcareous rock. It is quite inaccessible, and in its great height as well as in its extreme narrowness almost equals the celebrated gorge of the Trient.

Prof. Desor proposed for such gorges the special name of "Roflas."

Between Gampel and Raron the synclinal fold which has given rise to the Rhone valley divides; one branch diverges northwards through the Aar massif in the direction of the Aletsch glacier, the other has determined the line of the river.

The Swiss geological maps do not, unfortunately, show this very clearly, because the country north and south of the valley were mapped by different observers, and the strata are colored differently. There was, moreover, at first much, and is still some, difference of opinion as to the age of the Schists on the south side of the Rhone from Turtmann to Grengiols, which are colored light brown on Studer and Escher's map, violet on that of Heim and Schmidt, and dark brown on sheet 18 of the great Dufour map. These Schists are now generally regarded as Jurassic, and of the same age as the Jurassic strata on the north, which are colored blue and violet. The valley is in fact a trough of Jurassic strata lying between the older Crystalline rocks of the Aar massif on the north, and of Monte Leone on the south. The Aar massif is not, however, a simple arch, but is composed of several folds. The north side of the

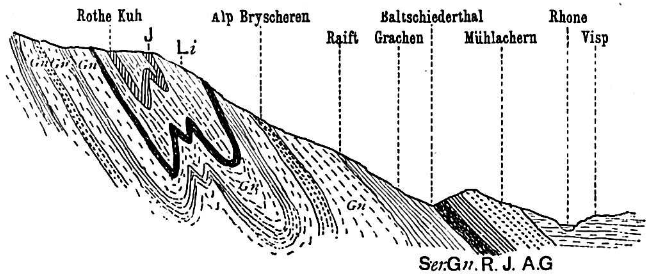


FIG. 117.—Section of the Rhone Valley at Visp. *Gr.* Granite; *Gn.* Gneiss; *A. G.* Eyed Gneiss; *Ser. Gn.* Sericitic Gneiss; *Li.* Lias; *J.* Jurassic.

Rhone from Gampel to Nieder Gestelen is cut down to the gneiss; from Nieder Gestelen to Baltschieder is a trough of Jurassic, at Baltschieder the gneiss appears again.

At Mund the trough, which is somewhat to

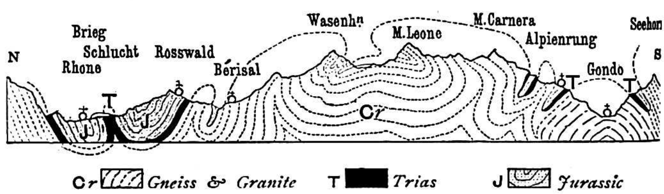


FIG. 118.—Section of the Rhone Valley near Brieg.

the south of the river, and dips to the south, again divides, and the two branches diverge; the southern takes the line of the Binnenthal, the Gries glacier, and the Bedrettothal, itself subdividing again on the way. Fig. 118 gives a section across the valley at Brieg. The northern synclinal has given rise to the valley of the Rhone, which follows its course.

Fig. 119 gives a section at Viesch. Denudation has here entirely removed the Secondary strata, though we may be sure that they must have formerly existed, since we find them along the valley both above and below.

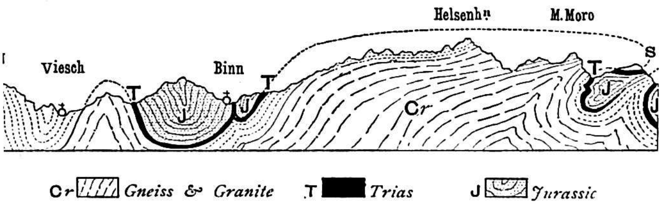


FIG. 119.—Section of the Rhone Valley at Viesch.

At Nieder Gestelen also is an old frontal moraine of the Rhone glacier, evidently deposited during its last retreat.

The valley of Zermatt, which opens at Visp, lies mainly in Schists, the exact age of which is still undetermined, but at Baarmühle there is a mass of Serpentine. The strata at Zermatt itself are considered to be Triassic. The gorges of the Görner resemble those of Ragatz or of the Trient.

The rock forming the upper part of the Matterhorn, is nearly horizontal, inclined slightly downwards towards Monte Rosa.

Heim regards it as an overlying fold of gneiss. It is a ridge like those of the Görner Grat and the Rumpfischhorn, and probably preserved by its position, and perhaps by being specially hard. The base is of Crystalline schists lying on Trias. On the west side is a wedge of granitic Euphotide.

The village of Randa has been several times overwhelmed by avalanches.

The Saasthal, which joins that of Zermatt at Stalden, is also wonderfully beautiful. Saas Fee and Zermatt are, however, so different that they can hardly be compared.

The inhabitants of the upper Italian valleys to the south of Monte Rosa have a widespread tradition of an enchanted valley, beautiful and rich, which once existed in the heart of the mountain, and has now disappeared. It is probable that the view of the Zermatt valley from the heights of Monte Rosa originated the idea of the lost valley; and certainly the more one sees of it the more enchanting it is.

If, as we ascend the Simplon route from Brieg, we look across to the Baltschiederthal on the opposite side of the Rhone valley, the contrast between the rounded outlines of the glaciated rocks below, and sharp jagged ridges of the Genthorn and the Gredetschhorn, the Hohen Egg, is very striking.

From Baltschieder to Mörel, with a small exception at the mouth of the Massa, the north side of the Rhone is Gneiss, while the south is Mica Schist. At the entrance of the Massa, however, and perhaps owing to its influence in bygone ages, the Rhone seems to have been forced somewhat to the south. However this may be it has cut through the Mica Schist, leaving a mass on the north side, which is bisected by the Massa.

For some distance above the mouth of

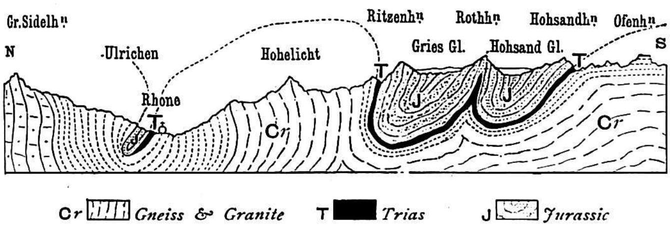


FIG. 120.—Section of the Rhone Valley at Ulrichen.

the Massa the valley is occupied by the débris of rockfalls. The blocks are scattered in wild confusion, and some are as large as cottages.

The Valais contains also several ancient moraines, one east of Filet opposite Zenhäusern, and a larger one between Lax and Wyler; but the most imposing is that east of Viesch. It partly forms the Gibelegg, forces the road to make several zigzags, and bears the village of Furgangen, extending towards Bodmen in the Viescherthal, and Belwald in the Valais. There is another large moraine at Ulrichen.

In the centre of the village of Biel is a great erratic block.

Above Biel the road crosses a great mound long grown over and covered with beautiful fields and meadows, but evidently the result of a prehistoric rockfall. The deep gash from which the mass fell is still clearly visible above Ritzingen.

Near Reckingen are remains of several ancient moraines, and at Münster another great rockfall, with its corresponding hollow like that of Ritzingen.

From Biel to Oberwald the lateral streams form a succession of cones, which drive the Rhone from one side to the other, and form marshy places by damming up the valley. Münster is built on a specially large one.

At Ulrichen Calcareous and Dolomitic rocks reappear; they are the continuation of the fold in the lower part of the valley. From Baltschieder to Ulrichen, however, they have been removed by denudation, which has cut down to the Crystalline rocks.

Above Oberwald the true continuation of the valley is up the little stream of Gingis. The larger one, which comes down from the glacier, is really a transverse affluent, but from its greater size is regarded as the source of the river.

In the wood through which the road rises from Oberwald to the glacier the rocks have been much worn and rounded by glacial action.

Just before arriving at the hotel the road enters another longitudinal valley, in which lies the beautiful glacier of the Rhone (see Frontispiece). At present the front of the glacier is about 20 minutes' walk from the hotel, the intermediate plain being an interesting illustration of fluvio-glacial deposits.

Like most of the Swiss glaciers that of the Rhone retreated during the first ten years of the century, after which it advanced and in 1820 reached within 150 metres of the houses at Gletsch, where it formed a small terminal moraine. From 1822 to 1844 it again retreated; then commenced another period of advance, and in 1855-60 the front was within 100 metres of the moraine of 1820. From that time it has again retreated.

Shortly above the hotel is the moraine of 1820, forming a well-marked curved ridge, which stretches across the valley, except where it has been cut through by the river. About 100 metres further is the moraine of 1855-60, which was the terminal moraine of the glacier when I first saw it. Then follows a stretch of irregular moraine matter, showing in miniature the same irregular heaps, which on a large scale we find near the moraines of the ancient glaciers. It is interesting to notice the difference between the angular rocks which have fallen with avalanches from the sides of the valley, and the rounded blocks which have been brought by the glacier. The larger of these often show a marked difference on the two sides, being (Fig. 36) rounded on the side turned to the glacier, and rugged on the other. Some of the blocks have evidently been pushed along by the ice, leaving a furrow behind, and making a little mound in front.

The river leaves the glacier in many streamlets, but mainly issues from a beautiful blue arch, now (1895) nearly in the middle of the glacier face, and some 25 metres high. The lower glacier is somewhat spoon-shaped, with radiating crevasses. Above it is a fine icefall, of which a splendid view is obtained from the road over the Furka; above the fall is a flat expanse of ice, ending in a great snow-field.

The Furka is a deep trough with gneiss on each side and Jurassic strata in the centre, marmorised by pressure, and containing Belemnites and Pentacrinites.

The synclinal is continued along the Urserenthal, and goes deep down, having been found with little change in the tunnel of the St. Gotthard Railway.

CHAPTER XVIII

THE BERNESE OBERLAND

THE Bernese Oberland seems at first sight a chaotic wilderness of mountains and valleys, snow-fields, and glaciers, without any plan or regular arrangement.

The more however the district is studied, the more the details are ascertained, the more do difficulties and anomalies disappear, and the points which still remain a mystery will doubtless be explained by future observations.

The Aar massif may be described as an ellipsoid mountain mass, running from S.W. to N.E; bounded on the N.E. by the Upper Reuss; on the S.E. by the Urserenthal and the Rhone from its source down to Leuk; on the N.W. by the great wall of the Bernese Oberland; and on the S.W. by the valley of Leuk. These lines of demarcation, however, though practical and convenient, are, it must be remembered, somewhat arbitrary. The valley of the Reuss is a transverse valley of erosion, cut out by the river, and the rocks on both sides are identical; it corresponds to no difference of geological structure. The valley of the Rhone is, on the contrary, a "geotectonic" valley, due to a great fold in the strata, but still geologically speaking of but recent origin. The great Bernese Oberland wall (Fig. 121) is an escarpment due to the weathering back of the Jurassic strata; and the valley of Leuk, like that of the Reuss, is a transverse valley of erosion.

Though the Aar massif is detached, it is no isolated phenomenon. The Protogine, which forms its nucleus, is mineralogically and chemically identical with that of Mont Blanc, and it is obvious that these two mountain masses are merely two upthrows of the same central rock.

Atmospheric influences and the agency of water have cut the slopes of the longitudinal ridges into deep valleys, thus forming transverse ridges, which again are carved by denudation into separate summits.

These ridges, therefore, form N.W. and S.E. chains, as for instance on the west of the massif, the ridge which runs from the Bietschhorn to the Dubihorn, or from the Nesthorn to the Fäschhorn and the Gredetschhorn; and on the east from the Schreckhorn and Lauteraarhorn.

The whole massif may be considered as the root or stump of a gigantic arch, itself thrown into a number of folds and troughs. The centre of the whole district is the majestic Finsteraarhorn, the monarch of the Bernese Oberland. To the N.E. are three main longitudinal valleys, indicated by the Gauli glacier, the Unteraar glacier, and the Oberaar glacier; and to the S.W. the great Aletsch glacier, the Aletsch Firn, the Upper Lötschen Thal,[1] and the Kander Firn.

The Granite and Gneiss as mentioned above (*ante*, p. 298) show a very complex structure, and the Central Gneiss presents a well-marked "fan arrangement."

Fig. 121 gives a section from the Kleine Doldenhorn across the Gasteren Thal and the Lötschen Thal, showing that the first is an anticlinal, the second a synclinal.

The Kander Firn and Tschingel Firn lie in an anticlinal valley. The Dala to the east of Leukerbad is also cut down between the Lias and the Upper Jurassic, the latter forming an escarpment.

The longitudinal valleys are, however, for the most part synclinal.

[1] The lower part of the Lötschen Thal is a cross valley.

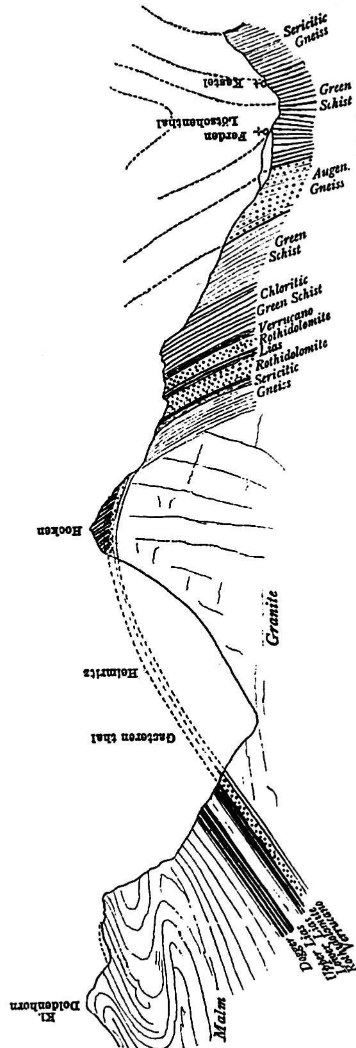


FIG. 121.—Section across the Aar Massif from the Doldenhorn across the Gasteren Thal to the Valley of Leuk.

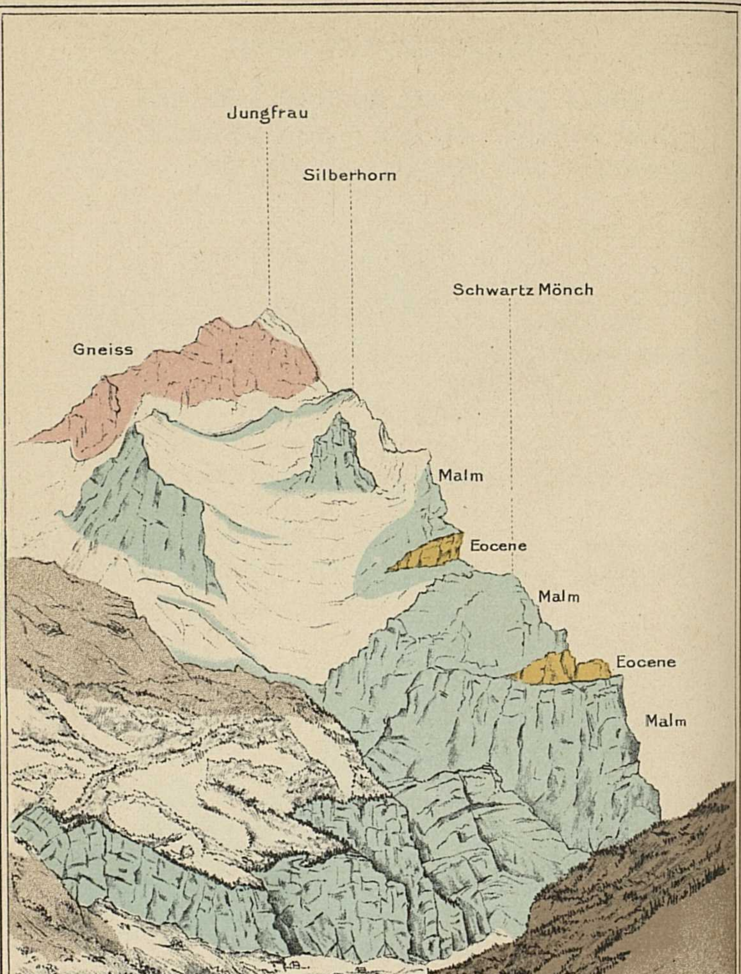
The Aletsch is the greatest of all Swiss glaciers. It is 15 miles in length and covers 50 square miles. It commences with a great snow sheet, the Grosse Aletsch Firn, the lower or N.W. end of which is known as the Concordia Platz. From this immense central snow-field radiate the Jungfrau Firn to the N.W., the Ewigschnee Feld to the north, and the Aletsch glacier to the S.E. The view from the Grosse Grünhorn is peculiarly arctic, for though it is very extensive, scarcely any trace of green is visible.

The Märjelen Thal falls in about the centre of the Aletsch glacier on the south side. If there were no glacier, the stream from this valley would join that of the Aletsch valley. The Aletsch glacier, however, occupies the great valley, and dams back the water of the lateral stream. The side of the glacier forms a cliff, 150 feet in height, and rising some 50 feet above the level of the Märjelen See. From this cliff great masses are detached from time to time, which float as miniature icebergs in the lake.

To prevent the water from rising too high a channel has been dug, which carries off the surplus down to Viesch. Every few years, however, some change in the glacier lets out the lake, which rushes under the ice down the Massa valley. The Märjelen See is quite unique. The pure white of the icebergs, the deep blue of the lake, the precipice of ice, the glacier, the green meadows and the surrounding mountains, make one of the most beautiful and extraordinary scenes in the whole Alps.

The view from the summit of the Eggischhorn has long been celebrated for its extreme beauty.

The Lötschenthal district is one of the most interesting and instructive regions in the whole Alps, and the contortions here attain their greatest complexity.



Lauterbrunnen.

View of the Jungfrau.

Though now therefore rising into mountains, they are really a closely compressed and folded trough.[1]

Fig. 123, representing the upper part of the Faldum Rothhorn, gives a vivid idea of the compression, contortion, and crushing which the mountain has undergone.

The remarkable, and long inexplicable, fact that on the Jungfrau and the Mönch the far more ancient gneiss overlies the Secondary Calcareous rock, is due to the existence of these great folds in the strata.

The west flank of the Jungfrau, as seen from the Ebnefluh, shows a great band of Calcareous rock lying on and covered by gneiss.

The Plate, representing the Jungfrau seen across the valley of Lauterbrunnen, shows the gneiss (pink) overlying the Jurassic (blue), in which are folded two wedges of Eocene (yellow).

This remnant of Jurassic rock, originally overlying, but now folded into the Gneiss, can be traced from the Jungfrau to the Petersgrat, on the northern flanks of the Ebnefluh, the Mittaghorn, Grosshorn, Breithorn, and Tellispitzen. It does not, however, extend through the mountain, but is, so to say, a wedge folded into it. Moreover, the wedge is itself folded, and contains two inner wedges

[1] Fellenberg, *Beitr. z. Geol. K. d. Schw.*, L. xxi.

The ridge of which the Ferden Rothhorn, the Resti Rothhorn, and the Faldum Rothhorn form three summits, is especially

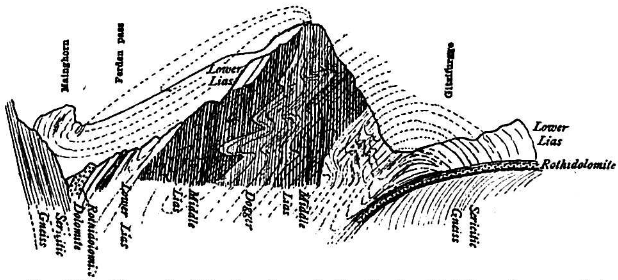


FIG. 122.—Theoretical Section through the Ferden Rothhorn from north to south.

remarkable. In Fig. 122 we see that the strata are very steeply inclined, and form a

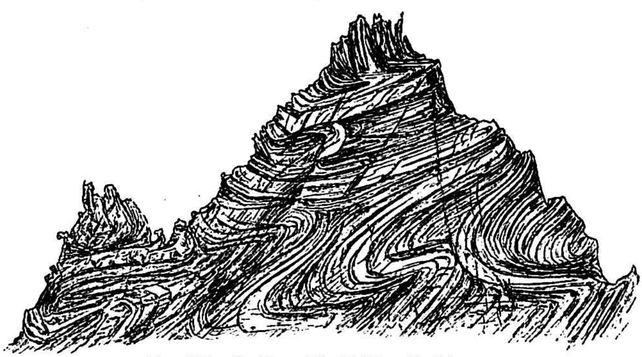


FIG. 123.—Section of the Faldum Rothhorn.

compressed synclinal fold, itself again several times folded. The centre of this trough now forms the summit of the Ferden Rothhorn.

of Eocene rock, which reappear near the hotels at Mürren, on the other side of the Lauterbrunnen valley.

Seen from the north the mountain appears as a wall of Calcareous rock, with a summit of Gneiss. The total height is 4167 metres, of which about 800 metres is gneiss, the base being Upper Jurassic.

The structure of the Mönch[1] is simpler, but it also belongs to the region of overfolded gneiss, which has a thickness of 900 metres, resting again on the Jurassic. The upper surface of the Calcareous rock is not horizontal, but inclined at an angle of about 20°.

In both cases the cap of gneiss is part of the great fold, and was originally continuous with the gneiss to the south and south-east. The Eiger, on the other hand, is a typically Calcareous mountain.

In the case of the Jungfrau the fold has a depth of 3 km., at the Mönch of $1\frac{1}{8}$, and in this distance the older and underlying Gneiss has been regularly folded over, so that it now lies upon the younger and originally upper strata. The Jungfrau wedge is regarded by Heim as the western continuation of the fold of the Windgälle. It had been supposed by some authorities that the Gneiss was thrust over the Jurassic, but Baltzer is clear that the inversion is due to folding and not to overthrust.

[1] Baltzer, *Beitr. z. Geol. K. d. Schw.*, L. xx.

In some cases the Calcareous rock seems to be forced into the gneiss; this, however, is due, not to eruption, but to kneading and squeezing.

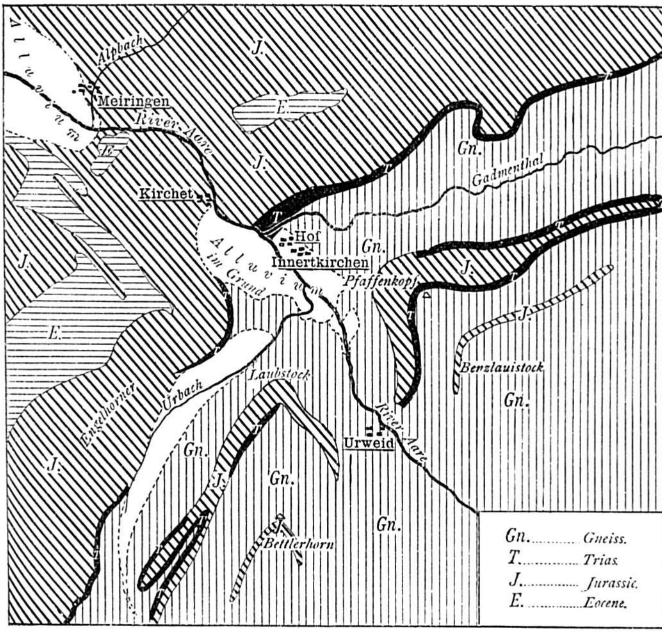


FIG. 125.—Sketch Map of Meiringen district.

Further to the west these great folds are well shown in the valley of the Aar. At and above Meiringen (see Map), the valley is excavated through the Jurassic strata, in which the celebrated gorge of the Aar has been cut through a belt of rock known as the Kirchet. Immediately above the Kirchet is a narrow band of older (Triassic) Sedimentary rock, and then we come to gneiss, the line of junction having the usual south-east and north-west direction. Further up the valley, however, is a second belt of Jurassic age, capping the Laubstock on the west and the Pfaffenkopf on the east, but cut through by the valley; while still further up, but at a greater height and consequently further from the valley, there is a second narrow band cropping out at the Bettlerhorn on the west, and the Stiergrund on the east, while the Schönalphorn, the Benzlauistock and the whole district beyond are gneiss.

The Jurassic strata originally covered the gneiss, and according to Baltzer they were thrown into folds, and these two belts of Jurassic are two of the wedges formed by the folds. Similar folds are shown in Fig. 120, but in that case have not been eroded. The valley itself, except just at Urweid, is on gneiss, above the gneiss is Jurassic, and over that gneiss again. The same arrangement is well seen in the Urbachthal which joins the main valley at Hof. It is one of the most beautiful, as well as most interesting in the whole district. The bottom of the valley is of gneiss, the west side (Engelhörner) is Jurassic, rising to a height of 1900 metres the right gneiss with however three bands of Jurassic (Malm) (Fig. 125); these are really the remains of folds as shown in the figure.

On the Gstellihorn there are actually five of these wedges or folds. It is in this respect the most remarkable case in the district.

The line of junction of the gneiss and the Calcareous rock is perfectly clear and sharp,

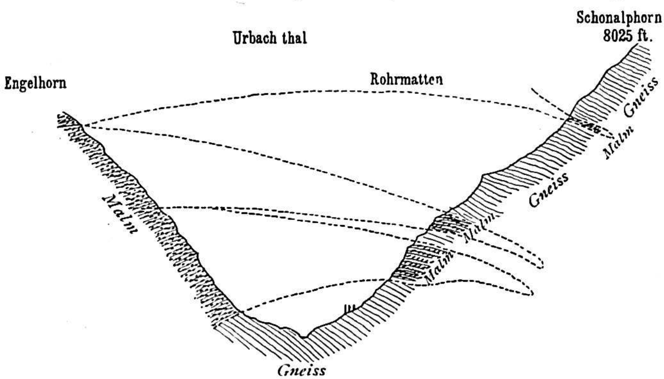


FIG. 126.—Section showing the calcareous wedges of the Schönalphorn in the Urbachthal.

so that the hand may cover both kinds of rock at the same time. There is absolutely no trace of any intermediate layer, such as marble, nor any change in the character of the Calcareous rock.[1]

It is evident, therefore, that the schists and sedimentary rocks have not been actively broken through by the granite and gneiss, but

[1] Fellenberg, *Beitr. z. Geol. K. d. Schw.*, L. xxi.

that they were deposited on them, all three having been passively and simultaneously thrown into folds.

The great wall of the Bernese Oberland (Fig. 121), which stretches eastwards from the Gemmi by the Balmhorn, the Doldenhorn, the Blümlisalp, the Eiger, the Mittellegi, the Scheideck, the Gadmer Fluh, and the Schlossberg to Erstfeld on the Reuss, with a nearly perpendicular height of 1000 metres, is in fact the escarpment of the Secondary rocks, which formerly covered the whole massif.

That these Secondary rocks once extended further south is clear from the dip of the strata (Fig. 121).

Moreover, some fragments of the Secondary strata still remain preserved in the deepest folds. At both ends of the ellipse Jurassic strata run up for some distance, as for instance, on the west, the Jurassic belt which quits the Valais at Raron and runs north-east by St. German, Leiggern, and the Krüliggrat towards the Hohe Egg.

To the east and west, however, these are cut off by denudation. Along the northern border of the gneiss, a series of Jurassic rocks extends at intervals from the Ferden Rothhorn by the Tellispitzen, on the flanks of the Breithorn, by the Ebnefluh, the Jungfrau, and Mönch.

More in the centre of the region another line commences with the Blauberg,[1] so called from the bluish Jurassic rock, which makes a striking contrast with the surrounding Crystalline region, at Farningen in the Meienthal, at Rothbergli, and at Staldi in the Intschithal.[2] Lastly, on the south comes the Jurassic fold of the Upper Valais.

Another evidence is that the northern transverse valleys, instead of tapering to the ridge, run boldly up to it, as for instance the Gamchi glacier at the head of the Kienthal.

Indeed, though the great wall is unbroken, blocks of granite and gneiss, which must have come from the central massif are found to the north of the wall.

The amount of denudation has therefore been enormous. The central peaks of gneiss and granite-gneiss, the Bietschhorn, Gr. Nesthorn, etc., tower up to a great height; but in our imagination we must replace on their summits, not only beds of Crystalline schists, such as those which form the Tschingelhorn, the Breithorn and the Finsteraarhorn itself; but over this again we have to pile the whole series of the Secondary strata, whose enormous thickness the great wall of the Bernese Oberland enables us partly to realise. Like the Titans of old we must pile Ossa on Pelion in our imagination, and realise that as in the

[1] On some maps it is marked as the Greissenhorn.

[2] Baltzer, *Beitr. z. Geol. K. d. Schw.*, L. xxi.

Greek myth, so also here it has been stripped off by the powers of the air.

The present configuration of the surface is therefore mainly the work of denudation, and while the longitudinal valleys are on the whole tectonic, the transverse or cross valleys which cut into and in some cases almost across the massif, the Trift glacier, the two Grindelwald glaciers, the Aar, the Reuss, etc., are valleys of erosion. The highest peaks are sometimes due to the greater hardness of the rock; sometimes, and perhaps even more, to the accident of their position which has exposed them less to the action of erosion.

The Aar massif, as Baltzer says,[1] is in fact a gigantic torso.

Indeed, any one who carefully considers the great wall of the Gemmi, or of the Blümlisalp, towering over the valley of Leuk and the Kander Firn, will be convinced that the Jurassic strata form the north limb of a great arch extending southwards.

These remarkable folds throw some light on the magnificent scenery and grand proportions of the Bernese Oberland. The Jungfrau and Mönch owe much of their beauty to the combination of gneiss and Calcareous rock. These, indeed, are exceptional instances, but the height is probably in great measure due to the extreme amount of compression and folding

[1] *Beitr. z. Geol. K. d. Schw.*, L. xx.

which has taken place. The enormous depth of the comparatively narrow valleys is another remarkable feature of the district. The steep precipices of the Wetterhorn have a height of 2000 metres. This also is greatly due to the same cause. The Calcareous rock (Hochgebirgskalk) which forms the lower part of the mountains is very inflexible. Folding might indeed take place at great depths, but near the surface there would be innumerable rents and fractures, which would reduce it almost to the state of a breccia, and leave it a comparatively easy prey to atmospheric influences.

CHAPTER XIX

THE UPPER AAR

THE Upper Aar from its source to the Hospice occupies a longitudinal valley. It is fed by the two great glaciers known as those of the Oberaar, and Unteraar. The Unteraar glacier, which is about nine miles in length and two broad, has, from its considerable size and level surface, been selected for many scientific observations. As long ago as 1827 Hugi built a hut on it, the remains of which were found by Agassiz in 1840, having moved forward about 4600 feet. In 1841 Agassiz himself built another hut on the glacier, long known as the Hotel des Neufchatelais. A peak visible from the Hospice has been named the Agassizhorn, in recognition of his valuable researches. At the Hospice the Aar turns northwards at a right angle into a cross valley. The rocks here, and down to Handeck, are remarkably glaciated, and the contrast between the lower portion, smoothed by the glacier, with the rugged and jagged rocks above is very marked.

At Handeck is the magnificent Fall of the Aar, certainly one of the finest waterfalls in Europe, from its height and the volume of water, the gloomy gorge into which it falls, and the wild character of the whole scenery. Moreover, the effect is considerably enhanced by the fact that another stream, the Handeck or Erlenbach, coming from the west, falls into the same chasm; and that from about ten o'clock to one in the day the spray reflects a beautiful rainbow.

The fall of Handeck is not, like so many others, a series of cascades, but the river leaps over with a single bound. This is due to the presence of a hard ridge of granite, which projects beyond the softer Gneiss-granite, and Eyed-gneiss.

Below Handeck, and as far as Guttannen, is a broad belt of Sericitic Phyllite. At Guttannen the Gneiss reappears and continues as far as Innertkirchen, broken however by another band of Phyllite at Urweid, and by the Jurassic folds already mentioned (*ante*, p. 372).

At Innertkirchen the Gneiss dips under the Triassic and Jurassic strata, the former represented by a narrow belt, the latter forming the continuation of the great wall of the Bernese

Oberland. Near the junction of the Gneiss and the Jurassic strata the Aar crosses a longitudinal valley, known as the Urbachthal (see *ante*, p. 372) on the west, the Gadmenthal on the east. In both cases the lateral valleys are at a higher level than that of the Aar, following the general rule that transverse valleys are excavated more rapidly than longitudinal, and the result is in each case a sharp rise from the Aar valley, that of the Urbach being the steeper of the two.

Below Innertkirchen the valley of the Aar is interrupted by a ridge of Jurassic rock, known as the Kirchet, above which it has been supposed that the river once formed a lake in the depression known as "Hasli-im Grund." Of this, however, there is no direct evidence, and it is possible that the river cut through the ridge as it rose. Studer[1] was disposed to regard the depression as due to an earthquake. In fact, however, it simply follows the normal slope of the river. The Aar has cut for itself a magnificent gorge, 300 to 400 feet deep, one of the longest and deepest in Switzerland. At both ends the rocks are much glaciated.

Near the upper end is a water-worn channel, which runs down by a steep path to the present river level. This is an old course of the river. The gorge of the Aar used to be

[1] *Geol. d. Schweiz.* vol. i.

regarded as due to fracture, but the whole section has evidently been cut by the river, and the characteristic marks of river erosion occur from top to bottom.

Below Meiringen the river flows through a broad flat valley, which was evidently once much deeper, and formed part of the Lake of Brienz. On each side are bold walls of Jurassic rock, with well-marked weather-terraces. As in other cases it is evident that the lake formerly extended some distance up the valley, in the present instance as far as Meiringen, and that it has been gradually filled up by the river.

The Lake of Brienz is 9 miles long, 2 wide, 566·4 metres above the sea, and 305 in depth. The lake follows the line of junction of the Cretaceous strata on the north, with the Jurassic on the south. Both sides are precipitous, and the celebrated falls of the Giessbach are near the east end, opposite Brienz, where the stream in a succession of cascades descends the steep wall of Jurassic strata. The ridge on the north is Neocomian capped by Urgonian.

The Lakes of Brienz and Thun were originally one, and the level plain upon which Interlaken stands has been formed by the deposits of the Lütschine coming from Grindelwald on the south, and of the Lombach which drains the valley of Habkern on the north. To judge from the depth of the lake, these deposits must be at least 1000 feet in thickness. It is said that until the fourteenth century the Lütschine ran into the Lake of Thun, and interfered with the outflow from the Lake of Brienz giving rise to an unwholesome marshy plain, and that the nuns of the Convent of Interlaken turned it into the Lake of Brienz. The Aar on the plain of Interlaken follows a winding course, being first diverted to the right by the cone of the Lütschine, and then to the left by that of the Lombach. The original lake, before it was divided by the formation of the plain, passed through a narrow gap in a fractured and displaced Neocomian ridge, very like that which nearly bisects the Lake of Lucerne at the two Nasen.

The position of the Lake of Brienz, like that of so many other longitudinal valleys, has probably been determined by its being the line of junction between two formations.

Grindelwald rests on a rockfall from the Röthihorn, which occupies almost the whole bottom of the valley.[1] To the S.E. of the church, however, a ridge of Dogger comes to the surface; while to the S.E. of the debris, and at the edge of the Jurassic (Malm), a narrow band of Flysch extends N.E. to Meiringen.

[1] Moesch, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.

The Grindelwald glacier formerly descended lowest of all the Swiss glaciers, the end being in 1868 only 1080 metres above the Sea. Of late years, however, it has considerably retreated. From Grindelwald the wall of the Oberland passes west to Meiringen over the Grosse Scheideck, and east to Lauterbrunnen over the Kleine Scheideck. At Lauterbrunnen is the beautiful Staubbach waterfall, one of the highest in Europe, the fall being between 800 and 900 feet. The height being so great, and the volume of water comparatively so small, it is shivered into spray before reaching the bottom, whence its name, the Dust Stream. "It is," says Byron, "in shape, curving over the rock, like the tail of a white horse streaming in the wind—such as it might be conceived would be that of the 'pale horse' on which Death is mounted in the Apocalypse. It is neither mist nor water, but a something between both; its immense height gives it a wave or curve — a spreading here or condension there, wonderful and indescribable."[1]

The Lake of Brienz occupies a longitudinal valley. Fig. 128 shows a section from north to south; from Guggenhürli across the Habkern valley and the Harder ridge to the Aar near Interlaken. It will be seen that the valley of Habkern is a valley of erosion, and that the Harder and Rieder Grat is formed

[1] Byron's *Journal.*

by Urgonian, Neocomian, and lower Cretaceous (Berrias) strata curving upwards towards the lake, over the present site of which they must at one time have formed a great arch. The present south edge of these strata is not their original boundary. They are not the shore of the cretaceous sea, but were formed in a sea which at one time stretched far to the south. The lower cretaceous beds in fact reappear in patches

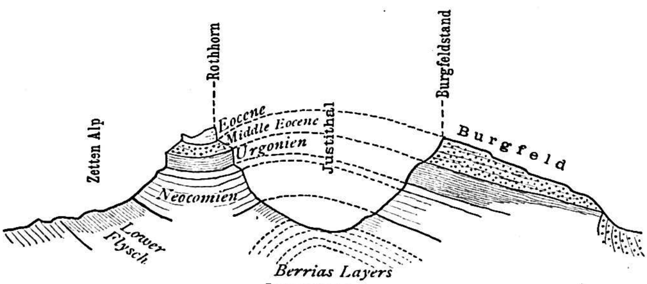


FIG. 127.—Section across the Justithal.

and bands along a belt running from near Gsteig, parallel to, but some distance south of the Lake; and the Eocene along another belt, from the Bay of Uri, by Meiringen, to Grindelwald. These must not be regarded as deposits formed in bays or fjords, but as remnants of once continuous deposits.

The valley of Habkern is also celebrated for many fragments and blocks of red granite, known as Habkern granite, which occur also in other neighbouring valleys, but are here particularly numerous. One of them attains a size of 400,000 cubic metres.[1] They are enclosed in the Flysch, and must therefore have been transported in Eocene times. No granite of this character is at present known in the Alps (see *ante*, p. 392).

Along the north of the Lake of Brienz is a range of hills known as the Harder. At

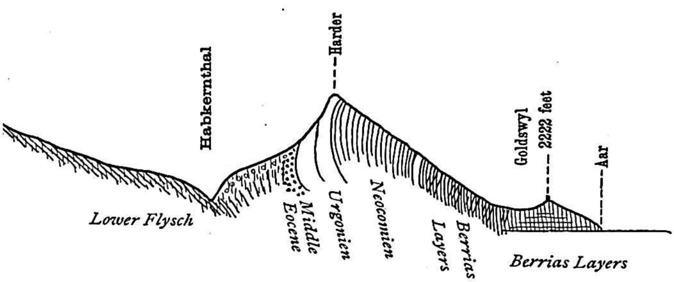


FIG. 128.—Section across the Habkernthal.

Interlaken they suddenly cease, but on the other side of the valley, and a little further to the west, is another similar range running in the same direction. These two are geologically similar, and are in fact parts of a once continuous range which has been dislocated and displaced. The strata composing it are inverted; the most ancient being at the top.

But though, no doubt, the Lakes of Brienz

[1] Kaufmann, *Beitr. z. Geol. K. d. Schw.*, L. xxii., pt. i.

and of Thun at one time formed a single lake, they are of a totally different character. The Lake of Brienz occupies, as we have seen, a longitudinal valley.

On the other hand, the Lake of Thun is for the most part a transverse valley of erosion. Fig. 127 gives a section across the Justithal, between St. Beatenberg and Sigriswyl, which, as will be seen, is an anticlinal valley.

The lower end of the Lake of Thun is dammed up, at any rate in part, by the deposits of the Simmen and the Kander. There is a curious point connected with the exit of the river Simmen (Simmenthal) from the mountains near Simmis. Instead of following the low ground between the Stockhorn (Jurassic) and the Niesen (Eocene), it has cut a gorge through the end of the former, detaching the Burgfluh (Jurassic) from the rest of the Stockhorn, of which evidently it formed originally a part. It is probable that this is due to the amount of debris brought down by the Höllengraben and other torrents coming down from the Niesen, which have driven the Simmen to the north of the Burgfluh.

CHAPTER XX

ZÜRICH AND GLARUS

THE Lake of Zürich is about 26 miles long and 3 in width, is 142 metres in depth and 409 above the sea. The immediate scenery, though not grand, is soft and rich, with a great air of comfort and civilisation.

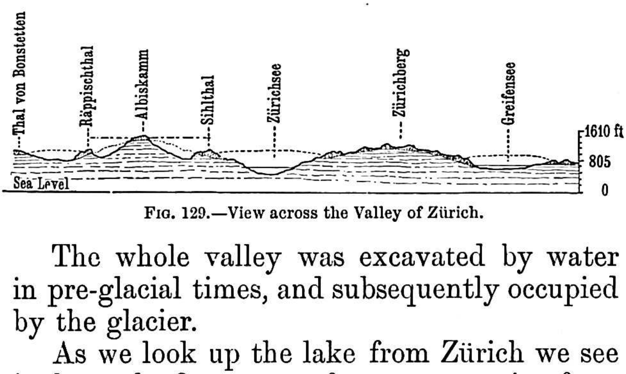


FIG. 129.—View across the Valley of Zürich.

The whole valley was excavated by water in pre-glacial times, and subsequently occupied by the glacier.

As we look up the lake from Zürich we see in front the fine range of snow mountains from the Glärnisch to the Windgälle and Titlis. The valley on the left is bounded by a ridge of Mollasse—the Zürichberg. On the right are two ridges. The nearer and lower one is the lateral moraine of the glacier during the last Ice Age; the upper ridge is the Albis, 1500 feet in height, and consisting of Mollasse and corresponding to the Zürichberg. The very summit of the Albis is also capped by glacial deposits, and the glacier extended at one time as far as Waldshut. The hotel on the summit of the Uetliberg stands partly on Mollasse, partly on the Moraine.

After a long period the climate improved, the glacier retreated, and the melting ice caused torrents which cut into and redistributed much of the material brought down by the old glacier, forming great fluvio-glacial deposits, more or less cemented together, and (see *ante*, p. 132) known as "Deckenschotter." Immediately under the restaurant at the summit of the Uetliberg is a considerable thickness of this deposit, forming perpendicular cliffs, under which are remains of ground moraine. The "deckenschotter" being pervious, and the ground moraine impervious, to water, springs occur at the junction of the two.

The glacier during the Second Ice Age also extended to Waldshut. It does not appear, however, to have stood very long at its extreme limit. The terminal moraine is unknown. To this period, however, belong the side moraines at Zugerberg, Hohe Ronen, Gubel, on the top of the Albis range, Hasenberg, Zürichberg, etc.

The moraines of the last Ice Age are, as might naturally be expected, more clearly marked, and have greatly determined the scenery of the district. The lateral moraine, as already mentioned, forms the low range of hills on the west of the lake, and separates it from the Sihl.

The outermost terminal moraine of the last Ice Age is perhaps that at Killwangen, below which is a mass of fluvio-glacial deposit, forming the so-called Wettingerfeld.

The next terminal moraine is just below Schlieren. Then comes the great moraine of Zürich; its highest points are the Muggenbühl, the hill of the Botanic Garden, the Lindenhof, the quarter known as Winkelwies, and the Hohe Promenade. Outside of the moraine is a great stratified mass of glacial deposits, and the whole forms a ridge which constitutes the lower lip of the Lake of Zürich. The river has cut through the ridge to a depth of 11 metres; the lake must therefore have formerly stood at that height above its present level, and joined the Lake of Walen, from which it is only separated by a flat plain.

The glacier during its retreat made another long halt at Wädenschwyl and Rapperschwyl, forming moraines, the latter of which reaches almost to the water-level, and has been utilised for the railway. It bears a number of erratic blocks, some, and indeed when the water is low many, of which project above the water-level.

The Lake of Zürich then is a drowned river valley dammed by a moraine. The valley of the Linth, as the Upper Limmat is called, is a cross valley, the upper lake from Utznach to Richterswyl is longitudinal, the upper portion of the lower lake crosses the strata somewhat diagonally, while the rest of the lake and the Lower Limmat is again a cross valley.

On both sides of the Lake of Zürich are a series of terraces, the upper ones reaching to a considerable height. They are especially conspicuous from Meilen to Stäfa, and at Horgen.

The valley itself, like the others which cross the Swiss low country, no doubt commenced in pre-glacial times. During, if not before, the first inter-glacial period it was excavated to its full depth, *i.e.* considerably below the present level, and partly refilled during the Second Glacial period. In preparing the foundation for the quay bridge at Zürich, the glacial deposits were pierced to a depth of 40 metres without reaching the bottom of the valley, and they are estimated at a thickness of over 100 metres.[1]

Indeed, unless there is some cross ridge of which we have no evidence, it follows that, as the lake has a depth of 142 metres, we may, even without allowing for any

[1] Du Pasquier, *Beitr. z. Geol. K. d. Schw.*, L. xxxi.

slope of the valley, assume that the dam of glacial matter must have as great a height, or, adding the 11 metres, no less than 675 feet.

I have throughout spoken of this valley as that of the Limmat. As a matter of fact, however, it was at one time occupied by the Rhine, and perhaps originally belonged to the Sihl; the Linth or Upper Limmat then flowed through what is now known as the Glatthal, until the great Rhine glacier, pressing westwards, drove it unto the then valley of the Sihl, and subsequently retreating left the Glatthal a deserted valley, only traversed by the little stream of the Glatt.

THE SIHL

With the history of the Lake of Zürich, that of the river Sihl is closely connected. Its course is curious, and its history very interesting.

Rising in the mountains of Schwyz it makes straight for the Lake of Zürich. At Schindellegi it is only 3 km. (less than 2 miles) from the lake, and no less than 350 metres, or 1150 feet above it. Here, however, the moraine opposes a barrier which the river has found insuperable, though it only rises to about 12 metres above the level of the stream, and the consequence was that the Sihl was diverted from its natural course.

The Upper Sihlthal, above Schindellegi, is a broad flat valley. The moraine of the Linth glacier, however, pushed the Sihl to the west and finally excluded it from its own valley. It flowed by Sihlbrück, and Baar, where a broad valley, now dry, leads towards the Lake of Zug. This was the second course of the Sihl. Its adventures, however, were not concluded. During the Third Ice Age the glacier of the Reuss occupied the Lake of Zug and gradually built up a moraine from Menzingen, east of Sihlbrück to Mettmenstetten and on to the north.

That this moraine belonged to the glacier of the Reuss is proved by pebbles of Eurite from the Maderanerthal, pieces of porphyry from the Windgälle and of Gotthard granite.[1]

The river thus dammed back, took the only course open to it, viz. its present bed between the Albis range and the great moraine on the west of the Lake of Zürich. The present—third—course of the Sihl, therefore, only dates back to the close of the glacial period. It is remarkable that similar conditions, though not so well marked, occur with reference to several of the other Swiss Lakes: thus the Kander has been dammed back from the Lake of Thun, and the Arve from the Lake of Geneva.

[1] Aeppli, *Beitr. z. Geol. K. d. Schw.* L. xxxiv.

The Walen See

The Lake of Walen, or Walenstadt, offers a great contrast to that of Zürich. It is about 10 miles long, $1\frac{1}{2}$ in breadth, 423 metres above the sea, and 151 in depth. The scenery is grand and stern. The south side slopes steeply, and the north is almost perpendicular, the cliffs rising to a height of nearly 3000 feet. As will be seen by Fig. 130, the strata are folded on themselves. Beyond them are extensive pastures, which rise to the edge of the cliff. The figure shows the remarkable contortions to which the strata have been subjected.

The district on the south, between the lake and the Rhine valley, has also been the seat of tremendous changes.

The Glarus Mountains

The district of Glarus is indeed one of the most interesting in the whole of Switzerland. If we ascend the mountains on the south of the Walen See we find everywhere the Verrucano as the basal rock; on it lie Röthidolomite, Lias, Brown Jura, Malm, Cretaceous strata and Eocene,—all, whenever present, in their regular order. But farther to the south all this is changed, and the strata are actually inverted. The newest rock, Eocene, is the lowest, and on it lie successively the Cretaceous, Malm, Brown Jura, Lias, Röthidolomite, and Verrucano, which caps several of the mountain summits. This inversion of the strata covers a space of over 1130 square km., and has long been a great puzzle to geologists. Escher, who studied the district with great care, came to the conclusion that the facts could only be explained by a great fold, turned over as it were so as to invert all the rocks. A similar inversion takes place on the south-east, so that there is a great double fold, starting from the Walen See on the north, and the Rhine valley,—say from Waldhaus Flims to near Chur on the south. The facts seemed so incredible that Escher hesitated to publish it. He told Heim that if he did, no one would believe it. The subsequent researches of Heim, which he has published in his two great works, the *Mechanismus der Gebirgsbildung*, and the twenty-fifth vol. of the Swiss *Beiträge*, seem to place it beyond a doubt.

The arrangement will be rendered clearer by the following section from the Walen See to the valley of the Rhine at Waldhaus Films, a little above Chur, which is given in Fig. 130.

On Butzistockli, a fairly accessible point to the west of the Karpfstock and east of the Linththal, Prof. Heim[1] shows that there

[1] Heim, *Livret Guide.*

is a complete series from Malm to Verrucano (Carboniferous), but in reversed order, the older rocks lying over the younger, and being reduced to about a tenth of their original thickness.

The inverted Verrucano caps several isolated, or almost isolated, summits, viz. the Haus-

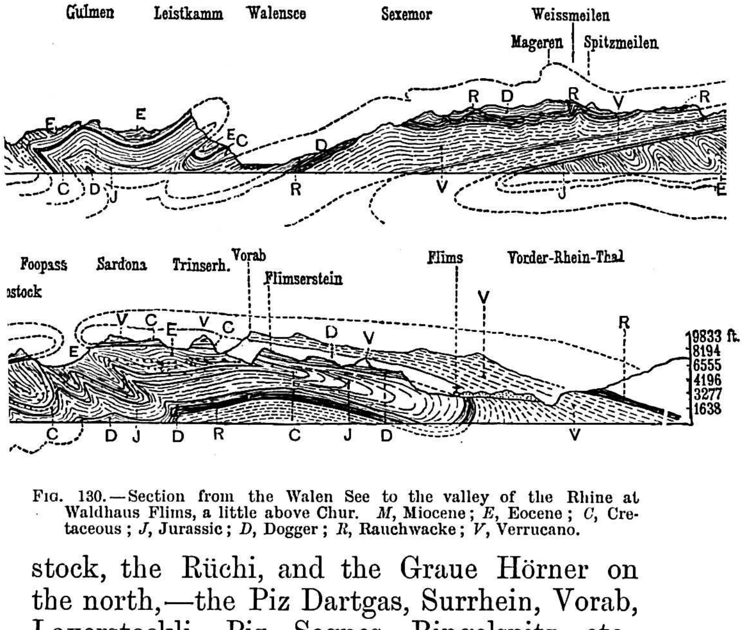


FIG. 130.—Section from the Walen See to the valley of the Rhine at Waldhaus Flims, a little above Chur. *M*, Miocene; *E*, Eocene; *C*, Cretaceous; *J*, Jurassic; *D*, Dogger; *R*, Rauchwacke; *V*, Verrucano.

stock, the Rüchi, and the Graue Hörner on the north,—the Piz Dartgas, Surrhein, Vorab, Laxerstockli, Piz Segnes, Ringelspitz, etc., on the south, and occupies a considerable district between the Linththal on the west and the Sernfthal on the east, in all these cases actually overlying the later rocks.

If this explanation be correct, the Verrucano, which caps the mountains as shown in Fig. 130, must be continued below. That this is so is proved by the section shown in the Tamina-thal at Vättis (Fig. 132), where the valley is actually cut down to the Verrucano. In the eastern district of the fold we find a similar case in the deep valley of Limmern-

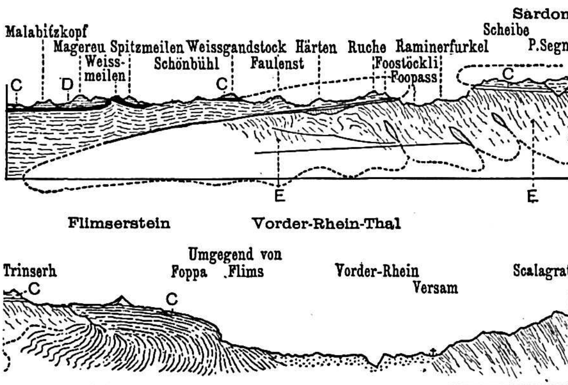


FIG. 131.—Section across the Vorder-Rhein-Thal from Weissmeilen to Versam.

tobel. Heim considers the views from the summits of the Hausstock, Ringelkopf, and Graue Hörner as among the grandest in the whole Alps.

That the Jurassic strata once extended far beyond their present limits is shown by Fig. 133, giving a section across the Stock-Pintga, where the fold has preserved a small outlier of either Lias or Brown Jura.

The sections (Figs. 131 to 136) really enable one to form clearer conception of the country than even a long description, and give a general idea of this interesting district.

The root, so to say, of the north fold extends from Fluelen by the Linththal to

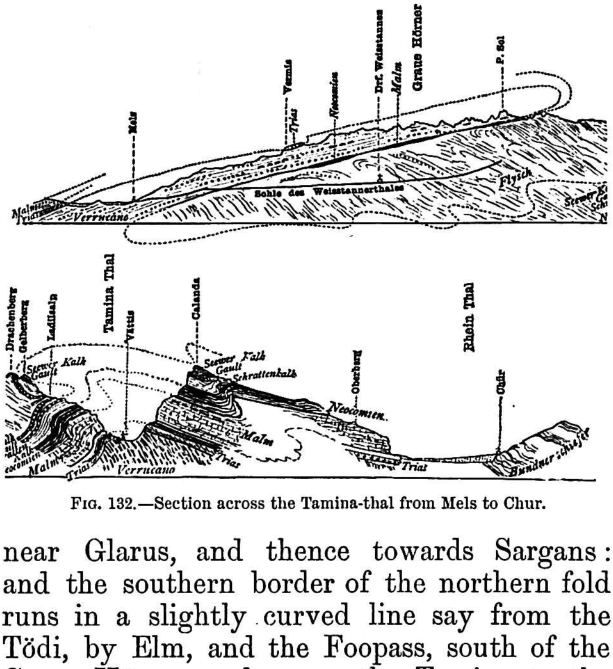


FIG. 132.—Section across the Tamina-thal from Mels to Chur.

near Glarus, and thence towards Sargans: and the southern border of the northern fold runs in a slightly curved line say from the Tödi, by Elm, and the Foopass, south of the Graue Hörner, and across the Tamina to the Rhine valley some distance below Chur.

The root of the south fold on the west appears first at Panix, and follows approximately the valley of the Rhine from near Truns to Chur, concealed, however, by immense deposits of gravel, etc. Beyond Chur it cannot be traced. The north border of the south fold lies somewhat south of the south border of the north fold. The fronts, so to say, of the two folds approach nearest at the Hausstock on the north, and the Kalkhorn on the south; and again (Fig. 131) at the Foostock from the north to the Piz Segnes on the south.

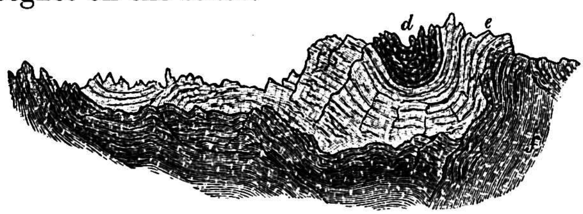


FIG. 133.—Section of the Stock-Pintga from Val Rusein. *d*, Brown Jura or Lias; *e*, Triassic Dolomite; *f*, Carboniferous strata.

The formation of the two folds was probably contemporaneous, though Heim considers that the south fold probably commenced first.

The effect of the double fold has been to shorten the distance between the Walen See and the Rhine valley by 32 km., that is to say from 67 km. to 35.[1] The north fold is 90 km. long with a maximum breadth of 16 km., the south fold 48 km. long with a maximum breadth of 13 km. Altogether the strata are reversed over a surface of 1130 square km.

[1] Heim, *Mech. d. Gebirgsbildung*, vol. i.

But though we thus get a general idea of this wonderful and interesting district, there are many questions still to be cleared up. The commencement of the folds to the east and west are still obscure, and the strata are in many places so crumpled, contorted, crushed, and metamorphosed that they can scarcely be recognised.

In many places the ridges are very sharp, and in the Vorab chain above Elm, in the Sernfthal, the steep calcareous strata form a wall 100 to 150 metres high, but very narrow. At one place the rock has weathered away, leaving an opening 16 metres high and 20 metres broad, known as Martin's Loch. It is so high over Elm that twice in the year, on the 4th and 5th March and the 14th and 15th September, the sun shines through it on to the spire of the village church.

But we may ask why is there this extraordinary amount of folding and contortion in the Glarus district between the Walen See and the Vorder Rhine? If the general explanation of the structure of the Alps which has been given in previous chapters be correct, it follows that the amount of folding in any section must be approximately equal. Now immediately to the east and west the great Glarus double fold is represented by a number of smaller ones. Further still it is replaced, and the necessary economy of space is obtained, by means of the Central Massives. In fact, if we look at the map we shall see that in the district of the Alps corresponding to the double fold, from the St. Gotthard on the west to the Silvretta on the east, there is no Central Massif. The Central Massif and the double fold are complimentary to, and replace one another.[1] In fact, in the Massives the central fold turns upward; in the Glarus double fold, downwards.

The district contains two remarkable cases of rockfalls. One belonging to prehistoric times, in the valley of the Linth, above Glarus, was from a cornice named Guppen on the east flank of the Glärnisch. The aspect of the valley between Glarus and Schwanden contrasts strikingly with that above and below. It consists of unstratified, more or less angular, debris of calcareous breccia, and the stones show numerous marks of concussion. It consists principally of Malm, with a small proportion of Dogger, Cretaceous, and Verrucano. It rests on and is covered by glacial deposits, and as in other cases dammed up the valley and formed a lake.

The other great rockfall, that of Elm, was

[1] Rothpletz (*Geotectonische Probleme*) has propounded another explanation, based on faults and overthrusts. Without wishing to dogmatise on so difficult a problem, the explanation given by Studer and Heim seems to me most in accordance with the facts.

the most disastrous which has occurred since that of the Rossberg. It took place on the 11th of September 1881 from the side of the Tschingelberg, at a height of nearly 3000 feet. Over 80 houses were destroyed and 115 persons killed. The place is still a scene of wild desolation :—

The Glärnisch

The Glärnisch is another complicated case of foldings.[1] It is both orographically and geologically a trough. The strata are folded on one another like an S cut off at the two sides by the valleys of the Linth and the Klön. Baltzer gives the following table showing the sequence of the strata on the eastern Glärnisch :—

Normal Sequence.	Actual Sequence on the eastern Glärnisch.
Eocene	Urgonian
...	...
Urgonian	Neocomian
Neocomian	Valenginian
Valenginian	Neocomian
Upper Jura	Urgonian
Middle Jura	Neocomian
Lias	Valenginian
Trias	Neocomian
Dyas	Upper Jura
...	Middle Jura
...	Lias
...	Upper Jura

[1] Baltzer, *Der Glärnisch.*

Normal Sequence.	Actual Sequence on the eastern Glärnisch.
...	Middle Jura
...	Dyas
...	Upper Jura
...	Eocene

It will be seen, therefore, that the folds are very complex. The Eocene, the most recent formation of all, is at the very base, and the folds have, in some cases, completely squeezed out particular strata. To the east of the Glärnisch is the Silbern, where Heim has found a similar structure, but even more magnificently developed.

WINDGÄLLE

The Windgälle group have been admirably described by Heim. The strata have not only been folded by pressure acting in a direction nearly north-east, but actually for a distance of $1\frac{1}{2}$ to 2 miles thrown back upon themselves (Fig. 134). The Porphyry, though an eruptive rock, is much more ancient, and has taken no active part in this remarkable overthrust. It has been perfectly passive, being itself folded with the other strata. The whole region is particularly instructive.

At the commencement of the Carboniferous period the older sediments, converted more or less into Crystalline Schists, contained already intruded masses of Granite, and were thrown into folds, forming a mountain chain. Over these sediments a mass of porphyritic lava was poured from some volcano or volcanoes, the site of which has not yet been discovered; and this lava was subsequently covered by another series of Carboniferous deposits. Before the Permian another period of folding occurred, and the folds were partly

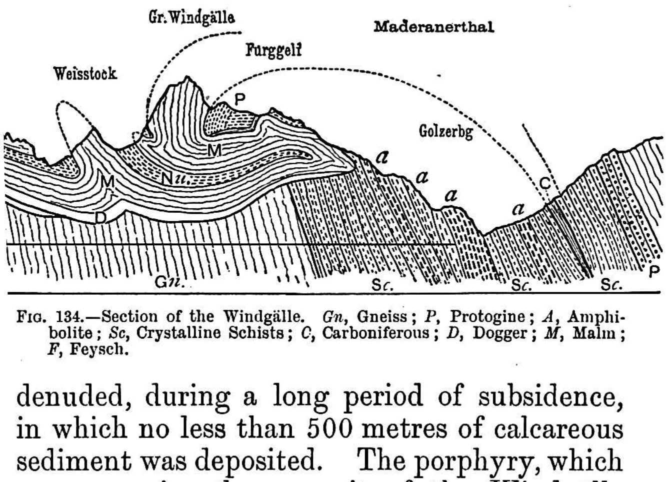


FIG. 134.—Section of the Windgälle. *Gn*, Gneiss; *P*, Protogine; *A*, Amphibolite; *Sc*, Crystalline Schists; *C*, Carboniferous; *D*, Dogger; *M*, Malm; *F*, Feysch.

denuded, during a long period of subsidence, in which no less than 500 metres of calcareous sediment was deposited. The porphyry, which now occupies the summit of the Windgälle at a height of 3000 metres, was then covered under a great thickness of Jurassic and Eocene strata. Finally came the foldings which have given rise to the present mountains, in which all the strata from the Carboniferous to the Eocene are folded conformably together.

CHAPTER XXI

THE RHINE

In previous chapters I have traced the great fold of Switzerland, not indeed from its commencement, but along the valley of Chamouni, over the Col de Balme, up the Rhone from Martigny to Oberwald, and over the Furka. It then forms the Urserenthal, and passing over the Oberalp, descends the Tavetsch and forms the valley of the Upper Rhine.

To the east the direct route to the Rhine valley would be by the Pass da Tiarms, north of the Calmot. The road, however, rises by a series of zigzags and passes to the south. On crossing the watershed the glen of Tavetsch opens out. It has a length of about 5 km., and on the north presents two terraces, one about 60, the other 2 to 3 metres above the river. The valley below terminates in a narrow gorge near the village of Sedrun. Below the gorge is a second broad stretch of valley, that of Dissentis, which itself is again closed by a second gorge below. Under the enormous gravel deposits of Dissentis are the remains of an ancient forest. The stumps of the trees, which are still upright, have in some places been exposed by denudation.

As in the case of the Rhone, so also here, the Swiss maps fail to convey a clear idea of the geological features, though for this they are not to blame. They naturally gave a separate color for the Bündnerschists on the south of the river, in which no fossils had been found, and the relations of which were consequently uncertain. Recent researches, however, indicate that these Schists belong to the Jurassic period, and correspond with the strata on the left of the river.

The Vorder Rhine, which may be considered as the true Upper Rhine, is generally stated to have its source in two small lakes, the Lake de Siarra, and the Lake Toma on the north flank of the Sixmadun. The tributaries which the Vorder Rhine receives on the north side are of secondary importance (see p. 181), but on the south it is joined by the Mittel Rhein at Dissentis, the Somvix at Somvix (Summus vicus, the uppermost village), the Valser Rhein or Glenner at Ilanz, the Rabiusa near Versam, the Hinter Rhein at Reichenau, the Plessur at Chur, the Landquart near Maienfeld, and the Ill near Feldkirch. The Rhine repeats to a certain extent, and for the same reason, the condition of the Aar below Soleure, which also on account of the general slope of the country receives all its important tributaries on the south.

Several of these streams are dangerous torrents, and are still rapidly deepening their valleys. For instance, the Glenner, which drains the Lugnetz, and falls into the Rhein at Ilanz, is in very active operation. Its valley is a deep notch, almost a gorge. The villages are situated high above the stream on an old river terrace, which in the lower part of the valley has a height of 1000 metres, and at Oberlugnetz of about 1500, above the water.[1] None of the lateral streams are able to form cones, all the material they bring down being swept away by the Glenner. Under the village of Riem the whole slope is in a most insecure condition, the houses are continually cracking and giving way, and have to be supported and restored.

The drainage area of the Upper Rhine was formerly larger than it is at present. The Italian rivers having a steeper course, have here, as elsewhere (for instance, in the Engadine (see p. 454), and indeed we may say along the ridge of the Alps generally), eaten their way northwards, invaded the Swiss valleys and carried off to the south certain streams which were originally tributaries of the

[1] Heim, *Beitr. z. Geol. K. d. Schw.*, L. xxiv.

northern rivers. The Scaradra, for instance, to judge from its upper river terraces, formerly ran by Motterasco and Greina, into the Val Somvix, and so to the Rhine at Surrhein. The Carassina again, which now makes a sharp turn and flows into the Brenno near Olivone, ran north into the Val Camadra and by the Greina Pass to Val Somvix. This suggestion may seem at first improbable, but river terraces can be traced to a height of 2200 to 2400 metres.

The upper part of the Rhine,[1] as far as Dissentis, presents many gravel terraces, which probably belong to the period when the river was dammed by the great rockfall of Flims. They are not mere river cones, but regularly arranged terraces, with a steep fall towards the main river. They carry us back to a time when the masses of debris which fell from the sides, or were brought down by the lateral streams, were subjected to a process of regular rearrangement, and they attain such dimensions that the villages all stand on this terrace. The present state of things is very different; erosion prevails over deposition, the lateral streams have cut, and every year are cutting, more deeply into the terrace, and the Rhine itself is undermining it, so that the houses have in many places had to be set back. The formation of these masses of

[1] Rütimeyer, *Eiszeit und Pleiocene auf beiden Seiten der Alpen.*

debris, their arrangement in a regular terrace, and the present period of removal, represent three different phases in the history of the river.

Though the general line of the river was probably determined by the great longitudinal fold of Switzerland, the exact course has been affected by various circumstances. It must be remembered that the river originally ran at a great height, at least 2000 metres, above its present level, and it is therefore by no means easy to ascertain what determined the exact line. Moreover, the strata not being horizontal, the centre of the present probably diverges more or less from that of the original valley.

The following figures will, I think, give

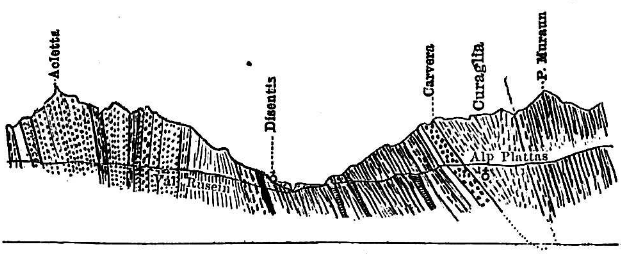


FIG. 135.—Section across the Rhine Valley at Dissentis.

a better idea of the structure of the Upper Rhine Valley than even a long description.

Fig. 135 gives a section across the valley at Dissentis. The river runs on a deep bed of recent deposits, resting on steeply inclined crystalline rocks.

At Somvix the structure is similar. The next figure (Fig. 136) gives a section at Truns, and shows the structure of the Bifertenstock and the Brigelserhörner.

From Truns to Ilanz the valley is excavated in Verrucano, which forms the root of the south wing of the great Glarner double fold (see *ante*, p. 394). Above Ilanz and below Chur the Verrucano is in its

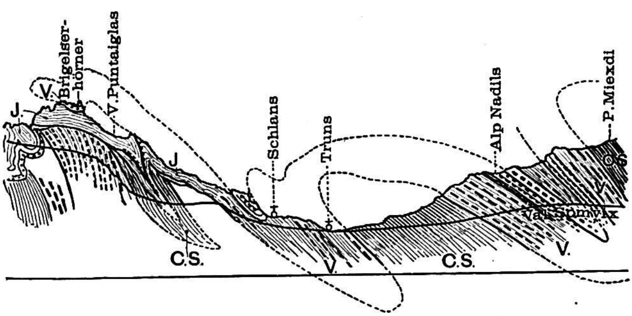


FIG. 136.—Section across the valley of the Rhine at Truns.

natural position, but between the two it is folded on itself.

Fig. 137 gives a part of the double fold on the Sardona and the great rockfall at Flims.

From Ilanz to Chur the river corresponds, not to a synclinal, but to an anticlinal zone; and if we consider its present position only it is difficult to understand the line it has taken. We must, however, endeavour to carry back our imagination to a time when it ran at a level say 2500 to 3000 metres higher. If we realise this and replace the strata which have been washed away, we should (see *ante*, p. 398) find ourselves in the fold at the base of the south wing of the Glarner double fold. This trough determined the original

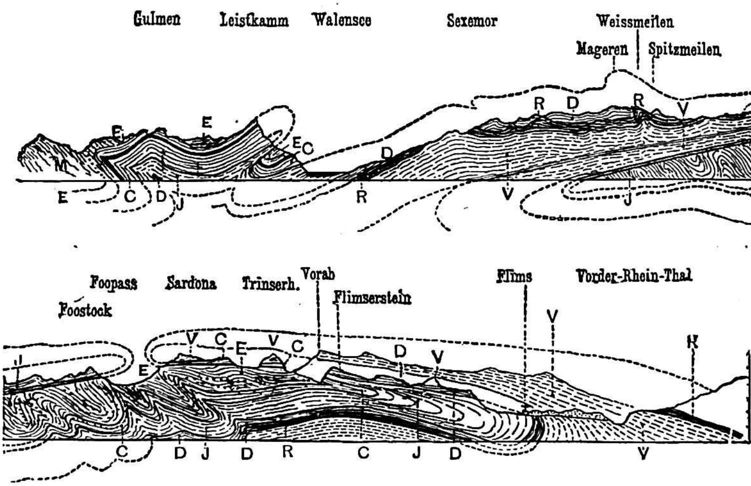


FIG. 137.—Section from the Walensee to the Rhine Valley at Flims.

direction of the river, which has cut down to the present anticlinal arch. Originally it occupied a synclinal valley, but its present condition is entirely the work of erosion.

Waldhaus-Flims stands far above the river, in beautiful woods, on the site of the greatest rockfall in Switzerland, the date of which is uncertain. The fall came from the Flimserstein, and the mass is no less than 700 metres in thickness. The Rhine has cut deeply into, but not yet through it. As usual with rockfalls the surface is very uneven, and contains several lovely little lakes.

At Reichenau and Bonaduz the old river terraces are specially well marked. The remarkable changes which appear to have taken place in the river-system of this region have been already alluded to (*ante*, pp. 187-188).

Symonds regarded the valley of the Averser Rhine as the finest example of high river scenery known to him. "Without," he says, "going into details of description I will say that I have never seen anything in the way of high river scenery to equal this. The Averser Rhine beats the Sesia and the Mastalone hollow, and has long odds against the streams of the Dolomites, which I have always thought enchanting. It has a tremendous volume of the purest azure water, which sometimes hides itself in cembratufted gorges, sometimes swims through grassy meadows with wide swirling curves that hollow out the turfy margin to their liking, sometimes carves a narrow monumental way through solid marble pure as Parian or Pentelican, sometimes falls thundering in cataracts encircled with a dozen changeful rainbows, sometimes glides deep and solemn in dark pools, which make one dream of death and long to dive in them and find the mystery."[1]

Below Reichenau are several remarkable hummocks in the valley, known as the Rosshügel, the origin of which has been much discussed. Heim regards them as the remains of a great rockfall.

The valley here is occupied by gravel, etc., of unknown depth. The conspicuous band in the cliff on the left side of the valley below Chur is Neocomian.

The upper part of Chur is built on the great cone of the Plessur. The Prättigau, which lies on the east side of the river from Chur to Maienfeld, is considered to be an area of subsidence.

Ragatz is celebrated for its hot springs and the gloomy gorge of the Tamina.

The valley of the Rhine at Sargans below Chur divides into two branches. At one time the river appears to have followed that on the left, and passing through the Lakes of Walen and Zürich to have occupied what is now the course of the Limmat and rejoined its present course at Waldshut. At present, however, it takes the right branch and so joins the Lake of Constance at Bregenz.

The ancient glacier of the Rhine extended

[1] Symond's *Biography*, vol. ii.

beyond the Lake of Constance and even invaded the valley of the Danube.

Here, as in the case of the Rhone, it is very interesting to see how the moraines retain their respective positions to the end. There are some characteristic rocks which are of very local origin. Guyot mentions[1] especially (1) the Porphyritic Granite of the Puntaiglas district, (2) the Green Granite of the Julier Mountains, (3) the Brown Gneiss of the valley of Montafun.

The Puntaiglas Granite keeps always to the west. One belt passes down the valley of the Lake of Walen, the other continues along the left bank of the Rhine valley to and beyond Winterthur.

The Green Julier Granite occupies the centre. It comes from the mountains over the Upper Engadine, down the Oberhalbstein Rhine and the Albula, is scattered over the Canton of Thurgau, along the west of the Lake of Constance, and far away to the north and east.

The Brown Gneiss of Montafun lies to the east. It comes down the valley of the Ill to the Rhine at Feldkirch, extends to the east of the Lake of Constance, and is abundant at Lindau, reaching far beyond Ravensburg.

Thus the Puntaiglas Granite is found only

[1] Guyot, "Sur la distribution des espèces de roches dans le basin du Rhone," *Bull. Soc. Neuchâtel*, vol. i.

on the west, the Julier Granite in the centre, and the Brown Montafun Gneiss on the east.

The Lake of Constance is 400 metres above the sea and 276 metres in depth; it is 40 miles long and covers 208 square miles. At its west end it is dammed up to a certain height by the deposits of the ancient Rhine glacier. This, however, would not account for more than say a quarter of its depth.

It is therefore a rock basin, and is, in Prof. Penck's opinion, as he has been good enough to inform me in a letter, due to changes in relative levels, or to excavation by the glacier.

Volcanic District of Hohgau

Volcanic phenomena play a very subordinate part in the physical geography of Switzerland. No doubt the masses of Granite, Porphyry, Syenite, Gabbro, Diorite, etc., sufficiently indicate the existence of plutonic forces, but the enormous denudation which has taken place has long ago removed all the surface rocks, leaving only "necks" or volcanic chimneys like those found in Scotland and elsewhere.

The district of Hohgau, north-east of Schaffhausen, is however an exception. Here there is a group of comparatively modern, but extinct, volcanoes (Fig. 138). Some are basaltic—Reidheim, Hohenstoffeln, Hohenhöwen; others are phonolitic — Hohentwiel, Magdeberg, and Hohenkrahen. They appear to have been Miocene, as phonolitic tuffs, probably derived from them, are interstratified with the freshwater deposits of Oeningen.

The hills rise to a height of 850 metres, steeply on the east and north-east. The tufa contains angular fragments of Jurassic rock, but no trace of any post-tertiary deposits. They are therefore post-jurassic; but although

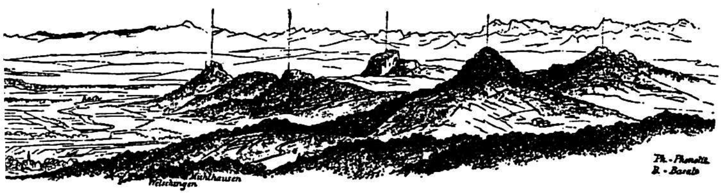


FIG. 138.—Volcanic group of the Hohgau. Seen from the north-west.

we find basaltic bombs, lava tears, ashes, etc., looking so fresh that one might suppose them to belong to an existing volcano, it is evident that the period of activity had already ceased before the glacial period.

Below the Lake of Constance the Rhine ran no doubt nearly in its present course even before the glacial period, but not exactly.

At one time it seems to have occupied the broad and now deserted valley of Klettgau. The present course has many marks of being comparatively recent.

Hence the bars of rock, one of which causes the celebrated and magnificent fall at Schaffhausen. This ridge regulates the height of the Lake of Constance, which would have been much lower if the Rhine had been running in its former bed.

The play and change of color at the falls is wonderful. In the early morning, as I have seen it from the Neuhausen side, the river above the falls looked like a smooth, undulating table of rock, from the ledge of which the water suddenly seemed to leap, as if the rock were struck by a Prophet. As the sun rose higher the upper river became a sheet of living silver, suddenly dashing down the falls like an avalanche, shot with green or springing up into the air in a shower of sparkling diamonds, tinged here and there with pink. By midday the upper reach of the river was deep violet, the lower water blue, gleams with green, and the white foam carried down into the depths showed much more distinctly, seeming to swim about in the blue like water spirits spreading out white arms.

In the afternoon the water above became almost black, that below green with scarcely any blue. Towards sunset it appeared again bluer, and the upper water lost much of its color.

In the fall itself there was less change from hour to hour. It was brilliantly white, and the water seemed to spring from rock to rock with restless glee. Towards evening, however, greenish tints appeared here and there.

At present the Rhine-falls appear to be undergoing little change. The oldest drawings and descriptions give very nearly the present details. This is mainly due to the absence of sand and gravel. The main work of the Rhine now is—accumulation between Chur and the lake; from the lake to the entrance of the Thur little change is taking place; and thence to Basle a slow cutting away and widening of the bed.

The celebrated quarries of Oeningen, at the west end of the Untersee, are in freshwater calcareous strata reposing on the Mollasse. Heer has described no less than 50 species of Vertebrates, 826 insects and 475 plants from these deposits.

The valley of the Rhine below Basle, as far as Mayence, is a band of subsidence as explained in the chapter on the Jura (see p. 252). The calm and yet rapid rush of the river at Basle is very impressive, carrying the freshness, and the cool clear waters of the mountains to animate and purify the plains of Germany and Holland.

CHAPTER XXII

THE REUSS

In previous chapters we have rapidly traced the great longitudinal valley of Switzerland from Chamouni to the confines of Germany.

We will now in the same way consider the two great transverse valleys of the Reuss and the Ticino, which cross the Rhone-Rhine Valley more or less at a right angle, thus dividing Switzerland into four approximately equal parts.

The remarkable evidence of glacial action presented by the Lower Reuss has been referred to in the chapter on Glacial Phenomena (*ante*, p. 109), the probable origin of the Lake of Lucerne has been alluded to in the chapter on Swiss Lakes (*ante*, p. 213), and the surrounding mountains in that on the Outer-Alps (*ante*, p. 281).

The Lake of Lucerne is 437 metres above the sea and is 223 metres in depth. From an ancient delta of the Muotta, and remains of terraces, it would appear[1] that the water once stood some 30 metres above its present level. It would then have formed one sheet with the Lake of Zug.

The lake itself, as its form clearly indicates, is no simple phenomenon, even like that of Zürich for instance, but is very complex. The surrounding hills at the western end are formed

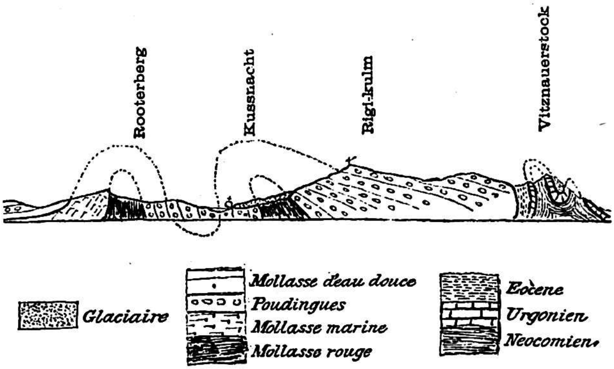


FIG. 139.—Section through the Rigi and Vitznauerstock.

of Mollasse, thrown as already mentioned into two main arches running S.E. to N.W. The ntermediate trough, or synclinal line (Fig. .39), between them, passes by Krienz, south f Lucerne, crossing nearly the middle of the ay, near Küssnach, across the Lake of Zug rom Immensee to Walchwyl, thence to Egeri, nd across the Lake of Egeri to Schindellegi. Both the Mollasse arches have their summits

[1] Du Pasquier, *Beitr. z. Geol. K. d. Schw.* L. xxxi.

razed. The Rigi and Rossberg represent the south wing of the south arch, and dip towards the lake. For the relation of the Rigi to the Vitznauerstock see *ante*, p. 286.

If we look at the map we shall see that the Reuss makes a considerable detour by Lucerne. The natural course would be by Schwyz, through the Lake of Lowerz, and the Lake of Zug, rejoining its present course by the valley of the Lorze. A slight relative elevation of

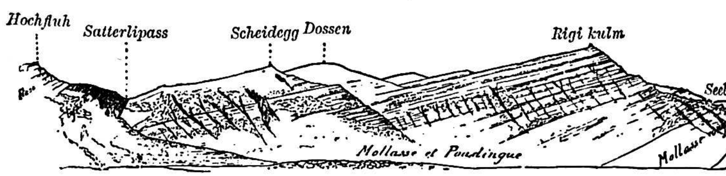


FIG. 140.—Slope of the Rigi from the north.

the country round the Lake of Zug, or rather a depression further south, probably gave rise to the change, forcing the Reuss to alter its direction, and overflow at Lucerne.

As already pointed out the old river terraces of the Reuss can still be traced in places below Zug, and (see p. 213) slope the reverse way to the valley. From this and other evidence we conclude that there has been a relative elevation of the land, which has dammed up the valley, thus turned parts of the Aa and the Reuss into lakes—the two branches of the Lake of Lucerne known as the Alpnach See and Urner See. The Bays of

Alpnach and Küssnach are in fact a continuation of the valley of the Sarnen Aa, which forms the Lake of Sarnen. The Bay of Alpnach lies in a synclinal valley between two cretaceous ridges which unite further west to form the Bürgenberg. Several of the smaller bays, as for instance those of Langensand and Winkel, are due to the existence of comparative soft and destructible strata. The Bay of Uri is a transverse valley, part of the course of the Reuss.

The Buochs-Brunnen-stretch is a trough,—perhaps the old course of the Engelberger Aa, when it joined the ancient Reuss at Brunnen and continued with it by Schwyz and Zug; the portion near Brunnen is, moreover, in a synclinal. The Wäggis-Vitznau basin on the contrary is a "combe." The Mollasse (Nagelflue) of the Rigi slopes to it on the north, and on the south it is bounded by the fractured arch of the Bürgenberg. The Bay of Lucerne is excavated in Mollasse, and is probably the most recent portion of the lake.[1]

The Lake of Zug has somewhat the form of an hour-glass, owing to a bed of hard puddingstone which crosses it obliquely to the north of Immensee.

The railway from Lucerne to Brunnen passes the scene of the remarkable rockfall of Goldau. The line passes between immense

[1] Rütimeyer, Der Rigi.

masses of puddingstone, and the scar on the Rossberg from which they fell is well seen on the left. The mountain consists of hard beds of sandstone and conglomerate, sloping towards the valley, and resting on soft argillaceous layers. During the wet season of 1806 those became soaked with water, and being thus loosened, thousands of tons of the solid upper layers suddenly slipped down and swept across the valley, covering a square mile of fertile ground to a depth, it is estimated, in some places of 200 feet. The residents in the neighbourhood heard loud cracking and grating sounds, and suddenly, about 2 o'clock in the afternoon, the valley seemed shrouded in a cloud of dust, and when this cleared away the whole aspect of the place was changed. The valley was blocked up by immense masses of rocks and rubbish, Goldau and three other villages were buried beneath the debris, and part of the Lake of Lowerz was filled up. More than 450 people were killed.

The Bay of Uri

The Bay of Uri used to be regarded as a typical valley of fracture. The bottom is, however, nearly horizontal, and it is evidently a river valley due to erosion.

The two sides (Fig. 141) are reflections one of the other, though, as the lake runs nearly north and south while the strike of the strata

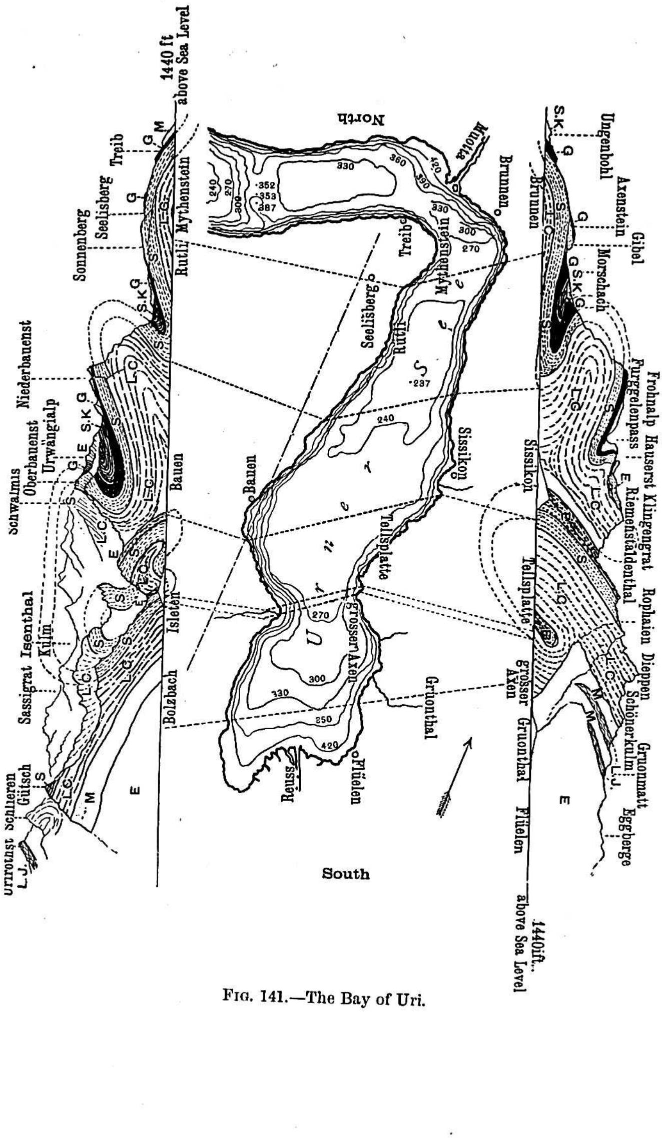


FIG. 141.—The Bay of Uri.

is south-west by north-east, the corresponding portions of the strata on the west side lie somewhat further south than those on the east.

Between Kindlimord and Schwybbogen a moraine covers the bottom of the lake, and rises within 50 metres of the surface.[1]

The walls of the Bay of Uri are formed mainly of Cretaceous strata lying on Jurassic (Malm, Dogger, and Lias), and thrown into various folds and arches.

As we approach Brunnen from the west, a magnificent arch of Neocomian capped (Fig. 141) by Urgonian (on which the hotels of Axenstein and Axenfels stand) may be seen at the commencement of the Axenroad, and on looking back from Brunnen the counterpart can be traced under Seelisberg. The strata are folded back upon themselves, over the summit of the Frohnalp (Fig. 141), and down again in a deep trough at Sissikon where the Cretaceous and Eocene strata are perpendicular. This great fold shows itself near Bauen on the opposite side of the lake, and the depression continues to the west up the Isenthal, and to Altzellen, south of Stanz, and eastwards by Riemenstalden across the Muottathal and up the Starzlen brook. The strata exposed at Sissikon by no means form the bottom of the fold. It continues much deeper, and then, according to Heim, turns up and reappears just beyond the

[1] Heim, *Beitr. z. Geol. K. d. Schw.*, L. xxv.

Tell Chapel, and at the opposite side at Isleten, where Eocene strata again occur. Such a contortion is almost inconceivable, but the marvellous foldings of the Neocomian strata, which we can see for ourselves, a little further along the road towards Stutzegg just before reaching Fluelen, are enough to convince us that it is not impossible, and Prof. Heim has certainly brought forward strong evidence in favour of his view.

The two "Mythen," which form a grand feature as we look up the Muotta Valley from Brunnen, consist of Jurassic and Triassic strata resting on Eocene. Their structure has given rise to much discussion. The Buochserhorn and the Stanzerhorn present a similar arrangement, and the probable explanation has been given in chapter xiii. (see p. 292).

Valley of the Upper Reuss

For some distance above Fluelen the valley is occupied by deposits of the Reuss. The living rock first appears at Amsteg, from which village to Attinghausen the road passes through a Flysch region of rich meadows and shady woods; from Attinghausen to the Bock brook about half an hour from Erstfeld is Hochgebirgskalk.

The valley above Fluelen has been admirably described by Rütimeyer, from whose memoir[1] most of the following details are taken. The Upper Reuss is a transverse valley, and in fact from Erstfeld to Luino on the Lago Maggiore, the strike and mineral character of the rocks on both sides of the valley are very similar.

The two sides indeed are so similar that in several cases line of fracture can be traced completely across the valley.

At Erstfeld the crystalline rock appears, mainly Mica schist, and micaceous Gneiss. As we look westwards—the jagged ridges of the crystalline rocks are in marked contrast to the softer outlines of the calcareous mountains.

From Amsteg to Gurtnellen the prevalent rock is Sericitic Gneiss, with lenticular masses of Amphibolite, which stretches away southwestwards by Guttannen to the Lauteraarhörner and eastwards to the Tschingel Glacier.

At Gurtnellen we come to Protogine, over which the Reuss flows nearly as far as the Devil's Bridge.

At Inschi, a little way above Amsteg, a reef of hard Gneiss crosses the valley obliquely. The Reuss is still engaged in cutting through this barrier. Its upper edge is covered by debris and vegetation, but the gorge of the river is 200 to 300 feet deep with vertical walls.

[1] *Über Thal- u. Seebildung.*

It will be evident to any one that this narrow gorge has been cut by the foaming water. Above it is the imposing summit of the Bristenstock, with a regular slope of over 2000 metres in height, except where it is indented by a river terrace, which will be again mentioned further on. As we ascend the valley we meet other Gneiss ridges, in some places at fairly regular intervals of 1000 feet,

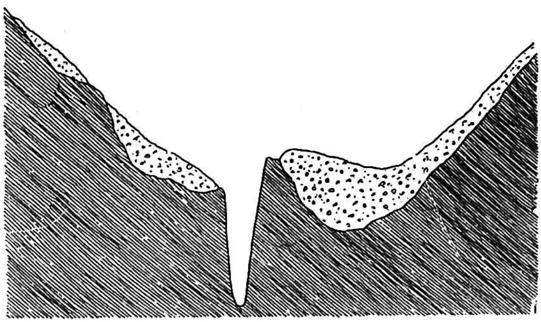


FIG. 142.—Section of Reuss Valley near Amsteg.[1]

evidently recurrent layers of specially hard rock. In proof of this it may be observed that each ridge has a weather and a lee side. The weather or upper side is sloping, ground and polished by the action of ice and water, while the side towards the valley has been left steep and rough.

Between two of these reefs the Fellibach falls into the Reuss.

[1] *Über Thal- u. Seebildung.*

The valley of the Reuss is here at a height of 713 metres. A very steep path leads up to the houses of Felliberg, beyond which the inclination becomes much gentler. The hamlet stands on a ridge at a height of 1543 metres, corresponding to the terrace above mentioned, which from this point of view can be clearly traced on the mountain sides both up and down the main valley. At the projections it generally bears the last winter dwellings (Arniberg, etc.). To it also correspond the

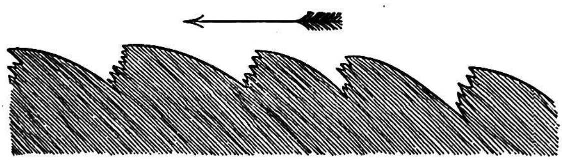


FIG. 143.—Reefs in the valley of the Reuss.

other side glens, which, with the exception of the Göschenenthal, the reason for which we shall see presently, like the Fellithal, after a comparatively gentle slope, drop rapidly into the main valley, so that from the Reuss the steep entrances are alone visible. The same difference of level between the main and the lateral valleys occurs in the Aar and other similar valleys. The steep inclines become shorter as we ascend the Reuss, and from a favourable point of view it can be seen that their summits form a common terrace with an inclination less steep than that of the Reuss, so that if we look down the valley it becomes gradually higher and higher above the present river; while on the other hand, if we look up the valley, they converge, finally meeting at Andermatt.

This "terrace" therefore commences at Andermatt; it can be traced along the main valley, as a line or ridge on the steep side, and descending gradually, though not so rapidly as the floor of the valley itself, but attaining much greater dimensions in the side glens.

It is obvious that this terrace represents a former "thalweg" of the Reuss with much less fall than it has now, and that the river has deepened its valley more rapidly than the lateral streams, so that these glens open at some distance up the side of the valley, and their waters join the Reuss by rapids or waterfalls.

The bridge at Pfaffensprung below Wasen leads again across a vertical gorge over 100 feet in depth. Here the Meien Reuss reaches the valley in a deep cutting from the high-lying Meienthal.

The Granite—or, as it is marked on the map, Granite Gneiss of the Upper Reuss—is vertically cleft in two directions approximately at right angles to one another, and is divided, moreover, into horizontal layers at tolerably regular intervals of 3 to 6 feet. This structure gives it a tendency—

also present, though less pronounced, in the Gneiss—to break into six-sided blocks. The Gneiss of the Ticino has a similar character.[1]

It is evident that the valley of the Reuss is a valley of denudation, and the factors which have determined its present configuration are rain and water, ice and frost, the character and structure of the rock, and lastly, the Reuss itself. The strata strike somewhat obliquely across the valley; they are nearly

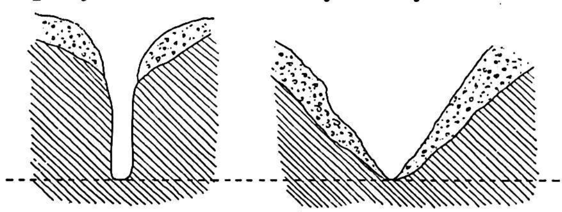


FIG. 144.—Section of the Reuss Valley.

vertical, and differ greatly in hardness, forming reefs across the valley. These ridges divide the valley into a number of small basins. They dam back the water, which gradually saws through them, and then with comparative rapidity drains the basin above. Rütimeyer represents the phases of this sequence in the accompanying diagrams, representing sections of the valley, which repeat themselves over and over again.

In Fig. 144, I, the river is sawing through the

[1] Rolle, *Beitr. z. Geol. K. d. Schw.*, L. xxiii.

rock. When this is accomplished, the process of widening begins and debris fall down from the sides (Fig. 144, II). Gradually the valley becomes occupied by debris, through which the river cuts a gorge (Fig. 145, III), and having done, begins again to saw through the solid rock (Fig. 145, IV).

Thus we have a succession of sawing, widening, filling, removal, and then sawing again.

Owing to the nearly vertical position of the

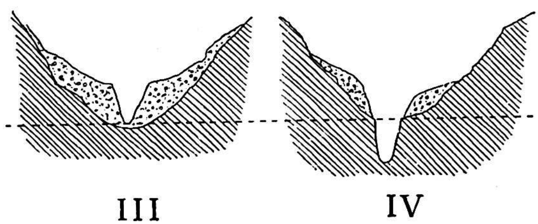


FIG. 145.—Section of the Reuss Valley.

rocks they present the same character from the highest peaks to the bed of the river, and we are brought irresistibly to the conclusion, however incredible it may at first appear, that the whole valley has been cut out by the river.

The Upper Reuss is evidently of great antiquity. It is older than the lateral valleys which drain into it, for it cuts across the ranges of mountains which divide them from one another. It must therefore be anterior to these chains, and we get an inkling how slowly they must have been raised, because the river must have had time to cut down into them during their elevation, so as to maintain its course.

The valley shows clear evidence of glacial action. The hard rocks are in places quite polished. This is especially the case with the buttresses which stand like doorposts where the lateral glens open into the main valley, and particularly on the right side of the eastern glens, the left of the western, where of course the pressure of the ice was greatest. Among the most beautifully polished are the left doorposts of the Göschenenthal, the Meienthal, and above all, the Gornerenthal.

The 1500 metre terrace is not, however, the oldest or highest. At a level of 2000 metres there is a terrace even more ancient, but still clearly visible, indeed the one which was first observed, and which was represented by Agassiz long ago in his view of the Bromberghörner. Above it the rock surface shows no trace of glacial action.

There is also a third less conspicuous terrace, at a height of about 800 metres, on which Gurtnellen stands, which represents the lowest level to which the ice has reached. Below it we find evidence of river action only.

We have then four "thalwegs," all rising to the south, but with very different inclinations, the steepest being the present Reuss Valley. They all converge upwards; the

Gurtnellen terrace joins the present Reuss level at Wyler, the terrace of the side valleys at Andermatt, the 2000 metre terrace on the shoulders of the St. Gotthard, at Monte Fibbia, and Monte Prosa.

These terraces are not of course continuous; in many places they have been washed away; they have been cut into by lateral torrents, but here and there they appear, sometimes on one side of the valley, sometimes on the other. These conditions indicate successive phases in the history of the valley—periods of comparative quiescence between others of more rapid excavation. The two most conspicuous are the present river course and the 1500 metre terrace. The other two represent former limits of ice action, the 2000 metres the highest level to which the glacier attained; the 800 metre terrace the level of the valley when the ice finally retreated.

Rütimeyer proceeds to consider the causes which gave rise to the phases of rapid action and relative repose, in which respect he regards the Göschenenthal as particularly instructive, and he concludes that the periods of repose represent those of great extension of the glaciers. This explanation may apply to what I would call the two glacial terraces, but not I think to the others. The 1500 metre terrace is probably the level of the valley at a former time when the river had acquired its regimen, and ran for a long period at this level. Then came a subsequent elevation; excavation recommenced, beginning at the lower end, and is still in progress; hence the difference between the slope of the terraces and that of the present valley.

The Göschenenthal differs from the other lateral valleys, as already mentioned, in opening to the Reuss Valley on a level.

Now why does this one valley differ in this respect from all the others? The answer is that it is a valley of a different character from the rest. They are due to lateral torrents. The Göschenenthal is a tectonic longitudinal valley, which is continued across the Reussthal, on the eastern side forming the Rienthal.

Prof. Heim has made an interesting calculation as to the annual denudation in the Reuss Valley. He estimates the yearly rainfall in the area drained by that river at 1,070,000,000 cubic metres, and the outflow of the river into the Lake of Lucerne at 750,000,000. The daily discharge of sand he calculates as about 150,000 cubic metres, to which he adds a quarter for finely divided matter. This would be equal to about 1000 waggon loads a day. According to his calculation then the average annual removal from each square kilometer of surface would be 242 cubic metres.

From the amount of material removed he calculates the ages of the terraces as follows :—

The first or oldest . .	1,150,000 years.
The second . . .	330,000 years.
The third	130,000 years.
The fourth . . .	23,000 years.

From the commencement of the excavation of the valleys to the present there would, he estimates, be required at the present rate of erosion a period of 3,750,000 years.[1]

At Göschenen is the entrance to the railway tunnel, and above it we soon come to the gorge of Schöllenen, a grand instance of the power of falling water. The road and the river here acquire their greatest inclination. The road winds round a colossal plate of Granite, whose immediate predecessor in numerous great fragments hangs over the river to the Devil's Bridge, and the Urnerloch is bored through a reef, which once extended across the valley. The gorge is so narrow, that an avalanche might well block it and flood the Urserenthal again, though happily this is unlikely.

The 2000 metre terrace is broad here, and intercepts most of the debris which fall from the Batzberg.

The Urnerloch is one of the wildest and most striking scenes in Switzerland. Unfortunately of late years it has lost much in human interest, first by the fall of the pictur-

[1] Heim, *Mec. der. Geb.* vol. i.

esque arch of the ancient Devil's Bridge, which perhaps was inevitable, and secondly by the construction of great fortifications which sadly mar the grandeur of the scene.

Certainly, as Forbes justly observed, "there is nothing more jarring to the impressions of stern grandeur and vast solitude than the not unfrequent occurrence of military works in many parts of the Alps."[1] I am far, however, from blaming the Swiss Government; the responsibility does not rest with them, but with the great military powers which, if they continue their present policy, will bring Europe to bankruptcy and ruin.

URSERENTHAL

On emerging from the Urnerloch we find ourselves on a most interesting spot. Suddenly the whole character of the scenery changes. We leave a narrow, wild, precipitous gorge, with a foaming river, more or less blocked by great masses of Gneiss and Granite fallen from the mountain sides above; we emerge on a tame, wide, flat, rather dreary plain, with totally different rocks; the whole physiognomy of the landscape is entirely different.

In fact we find ourselves in a valley

[1] *Travels through the Alps.* When I was last there the rocks were also desecrated by some monstrous advertisements. It is to be hoped, however, that these are only temporary.

of another character, and belonging to a different order of things. We have left a transverse, and find ourselves in a longitudinal, valley; we have left a live, and find ourselves in a dead, valley. The Urserenthal is a part of the great longitudinal Rhine-Rhone fold which traverses Switzerland from east to west, cut off as it were by the Furka from the Rhone, and by the Oberalp from the Rhine. It is geologically a deep trough of Secondary strata (see Fig. 9) forming a fold in the crystalline rocks. The width of the Urserenthal is partly due to the softer character of the sedimentary rocks. Above Andermatt is a small wood, which has been left as a protection from the avalanches.

Above the Gallery on the left side of the Reuss, and in the Teufelsthal itself on the right side, there is a layer of Sericitic Gneiss about 300 metres thick. The Protogine ceases at the south opening of the Urnerloch, and is followed by about 500 metres of Chloritic and Sericitic, often Quartzose, vertical Schist, which encloses a pointed trough of Secondary rock (Triassic and Jurassic). The Oberalp road is on Gneiss, but at the third turning is a deposit of black, graphitic shale 65 metres in thickness.

Near Hospenthal are several quarries in grayish black Lias containing Belemnites. The Furka Hotel stands on Jurassic strata, which can be traced, with one or two breaks, to Ulrichen in the Rhone Valley.

The fold must descend to a great depth, for it was met with and traversed by the tunnel, (Fig. 93) which here is 300 metres below the surface.[1]

From the Urnerloch to Hospenthal the two valleys cross one another diagonally, and at Hospenthal the cross valley leaves the Ursenthal and ascends the St. Gotthard.

We leave also the band of sedimentary strata and find ourselves again on crystalline rock. The broad saddle of the pass is seldom entirely free from snow; it is a wilderness of ice, and snow and rock, a sort of granite marsh.

St. Gotthard

The central mass of the St. Gotthard is a more or less elliptic mountain chain, whose ridge and highest summits lie much nearer the south than the north boundary. It is crossed by two long depressions. One begins in the Upper Glienthal, passes by the Wyttenwasser glacier to the Lake of Lucendro, from there to the Fortunerthal and the Sella See, the Val Torta and the Canariathal to the Val Cadlimo.

The summit is of Gneiss belonging to the

[1] Fritsch. *Beitr. z. Geol. K. d. Schw.* L. xv.

variety known as Fibbia Gneiss. The strata strike parallel to the Urserenthal, and at the summit are vertical.

North of the Hospice the Gneiss dips to the south, at the Hospice and on Monte Prosa it is perpendicular, while south of the Hospice the dip is northwards, the south wing being, however, smaller than that to the north. This arrangement therefore gives a typical illustration of the celebrated fan-like structure.

The Protogine of the St. Gotthard closely resembles both in chemical composition and microscopical structure that of the Aar massif, and they are probably continuous.

At and surrounding the Pizzo Rotondo is a mass of Granite, which appears to be intrusive. It is evidently less ancient than the Gneiss, since it contains angular masses of that rock.

From the St. Gotthard radiate six important rivers: the Rhone to the W., the Rhine to the E., the Reuss to the N.E., the Aar to the N.W., the Ticino to the S.E., and the Toce to the S.W., and though the summit does not attain the same wildness or elevation as the heights of some other mountain districts, it presents all the other charms and interest of alpine scenery, and is especially interesting as the central point of the Swiss Alps.

CHAPTER XXIII

THE TICINO

THE valley of the Ticino, or the Val Leventina, corresponds on the south of the Alps to that of the Reuss on the north. Below Airolo to Bellinzona the river runs, like the Reuss, in a cross valley, it follows in the main the same direction, and like it is cut through crystalline rocks. It is of similar age, and is a valley of denudation, a child of the same rain and storms.

At Airolo it crosses a longitudinal valley, which to the east is known as the Val Piora, and on the west as the Bedrettothal, just as the Reuss crosses the longitudinal valley of Urseren, and is joined by the brook from the Oberalp on the east, and the Realp-Reuss from the west. In both cases the stream coming from the west is the most considerable. That which drains the Bedrettothal is generally considered as the Upper Ticino, but the direct continuation of the Leventina is up the stream of the Tremola.

Yet though the Val Leventina corresponds in so many respects to the Reussthal, in some respects they present great contrasts, and as we cross the pass the scenery changes like magic. The two valleys are, in the words of Rütimeyer, twin brothers indeed, but brought up in a different climate, and clothed in a different dress.

The valley of the Ticino, in the boldness of its features, the grandeur of its dimensions, and the beauty of its coloring, has certainly no superior in the whole Alps.

From the quantity of snow which falls in the upper valley, the frequency of avalanches, and the character of the rock, we see here the effects of denudation on a scale which cannot be exceeded, and can hardly be equalled, elsewhere.

Below Airolo the valley is divided into successive stages separated from one another by narrow gorges, corresponding to the sections already described in the northern valley: (1) The short piece between Airolo and Stalvedro, which really forms part of the Bedrettothal, corresponds to the Urserenthal on the north side of the mountains: the gorge at Stalvedro is due to a ridge of Gneiss; (2) the section from Stalvedro to Dazio Grande; (3) from Monte Piottino to Calonico; and (4) the broad river valley, which again may be divided into sections from Chironico to Biasca,

Biasca to Bellinzona, and Bellinzona to the Lago Maggiore.

The river terraces (Fig. 146), or at any rate several of them, are well marked in the Val Leventina, sometimes in small detached pieces, sometimes in larger stretches rendered conspicuous by the white Campanile of the

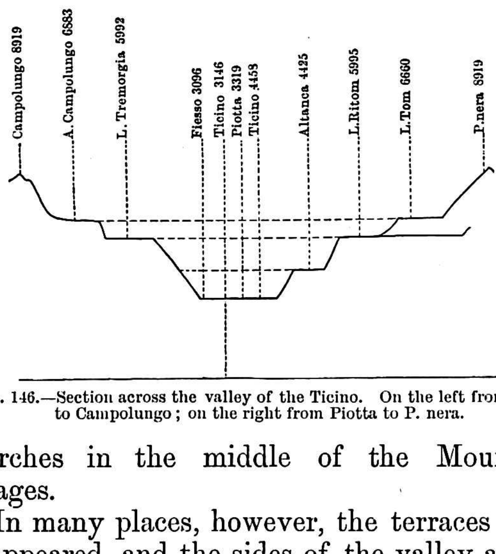


FIG. 146.—Section across the valley of the Ticino. On the left from Fiesso to Campolungo; on the right from Piotta to P. nera.

churches in the middle of the Mountain villages.

In many places, however, the terraces have disappeared, and the sides of the valley are so steep that those which remain are far from secure. The valley has been the scene of many catastrophes caused by parts of these terraces slipping down bodily into the valley.

The best preserved terrace is that which belongs to the level of the Bedrettothal. It diverges from the present valley level at Madrano, and bears also the villages of Altanca (1392 metres), Ronco (1373), Deggio (1214), and Catto (1244). It corresponds with the terrace of Andermatt on the Reuss. In spite of the destructive glacial action it can be traced round Monte Piottino, and below it again forms a broad terrace, visible even on small maps, as bearing the villages of Osco (1164), Mairengo (923), Primadengo (975), Rossura (1056), Calonico (987), Cavagnano (1021), and Sobrio (1095). Calonico is celebrated as the seat of the terrible catastrophe of 28th September 1868. From Altanca to Sobrio this terrace drops 300 metres, while the present river valley falls 900 metres. Here also, therefore, the figures closely correspond with those of the Andermatt terrace in the valley of the Reuss.

The terrace, though not so continuous, can also be traced on the right side of the valley, where it supports the hamlet of Nante, and the Alps of Ravina, Prato, etc., as far as Chironico.

Above this terrace is a yet higher one, (Fig. 146), specially well marked to the south of Monte Piottino. It supports no church villages, but some winter dwellings, as Ternolgio (1590), Molare (1500), Matengo, etc.

Higher still is the upper glacier boundary, which, however, is only visible on some of the highest peaks on the right side of the valley, while the left side soon dips below it.

As in the valley of Uri, so here again it is possible also to trace the lower glacier level. It is clearly marked at the opening of the defile of Dazio, and below it is the narrow groove due to the sawing action of the river.

At Monte Piottino the sawing has not even now progressed sufficiently far to enable the river to act fully on the part of the valley above. On the other hand, the same cause has increased the fall and consequently the erosive power of the water below, and the position of Biasca is in consequence probably somewhat lower than would otherwise have been the case.

The same conditions repeat themselves at Chironico, and we may look forward to a time when the lowering of the ridge here will drain the basin of Faido, deepen the cutting at Dazio, and even affect the Bedrettothal.

Shortly above Biasca an enormous rockfall took place in 1512. It closed the mouth of the valley of Blegno ; and from the railway the great scar on the mountain is clearly visible.

The following profiles, giving sections of the valley, represent the successive phases in its history ; part II. has passes through stage I., part III. through both the preceding.

Below Chironico the river ceases to excavate, and is now filling up the valley. Beautiful

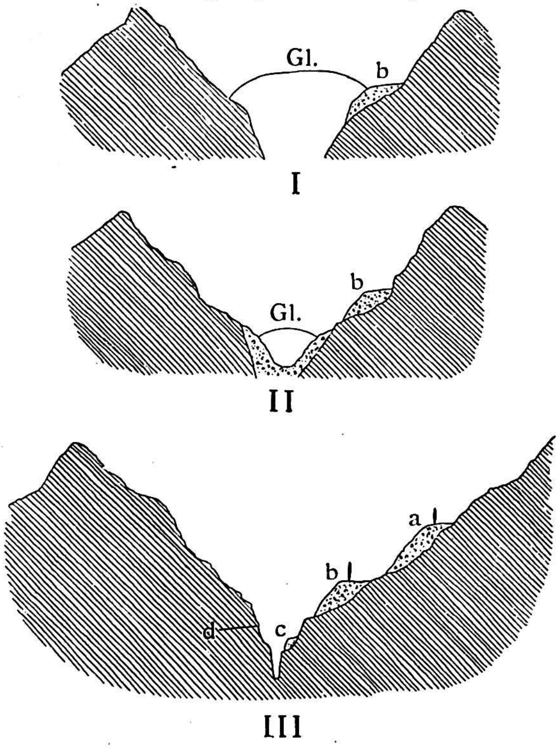


FIG. 147.—Cross Sections of the Valley of the Ticino. I., Bedretto; II., Piotta; III., Faido. The dotted line Gl. represents the former glacier; *a* is the terrace of Molare (1500 metres); and *b* that of Altanca, at Osco (1160 metres); *c* is the beginning of a new terrace; *d* is the lower line of the former glacier.

evidence of its former action, however, still remains in the smooth concave surfaces of rock, 150 feet above the present water level, near the second bridge which carried the old road over the river. These can easily be distinguished from the more completely polished but convex surfaces, characteristic of ice action. They are very well shown at higher levels, and there are few more imposing remains of glacier action than in the Ticino Valley. As in the Reuss, the "Doorposts" of the lateral valleys, as for instance at Osogna, Cresciano, Lodrino, and Moleno, are highly polished. It is striking to find these clear proofs of ancient glacier action, not only among the Chestnuts of Osogna, but even further down the valley among the vineyards of Bellinzona, and the Cypresses, Olives, and Orange groves of Locarno.

And this brings us to another feature which makes a great difference in the general appearance of the valleys of the Reuss and the Ticino. In the former we have dark fir forests, gradually giving place to beech and oats, then mixed with chestnuts and wheat.

In the latter we have chestnuts and wheat, then vines on wooden trellises supported by pillars of Gneiss or Granite, passing more and more into the luxuriant vegetation of the south. This plan gives easy access to the fruit, and the ground is not exhausted as it is when the vines are grown on trees. Moreover, the gneiss, though white when freshly fractured, rapidly assumes a rich brown tint, and weathers into rounded tower-like forms. The houses also assume more and more the characteristic Italian style of architecture, so different from that of the Swiss chalets.

The Canton of Ticino, and indeed the whole district south of the Alps from Domo d'Ossloa to Chiavenna, consists mainly of crystalline rocks, generally Gneiss, and more or less steeply inclined, being thrown into a number of folds, which, however, require much further study.

The Secondary rocks have been almost entirely removed by denudation,[1] but their former existence cannot be doubted, and remains still exist, though so much metamorphosed as to be hardly recognisable, nipped as it were into some of the deeper folds. They are still, however, notwithstanding the pressure they have undergone, more destructible than the crystalline rocks, and often give rise to valleys, as for instance the trough which forms the Val Bedretto and crossing the Ticino the Val Piora; or the Rheinwaldthal at Splügen.[2]

One of the most important of these folds forms the valley of the Ticino from Locarno to Bellinzona, where it bifurcates, one branch forming the Bregaglia, the other the Lower Val Tellina.

At present, indeed, the Lower Val Tellina

[1] Rolle, *Beitr. z. Geol. K. d. Schw.*, L. xxiii.
[2] Studer, *Geol. d. Schweiz.*, vol. i.

seems to be (Fig. 148) an anticlinal valley. But if we carry back our imagination to a time before denudation had proceeded so far, it is evident that the present valley once followed the line of the inclined synclinal of Cino. This is also illustrated by Fig. 57 (*ante*, p. 183).

One belt of sedimentary strata, now, however, much metamorphosed, can be traced the

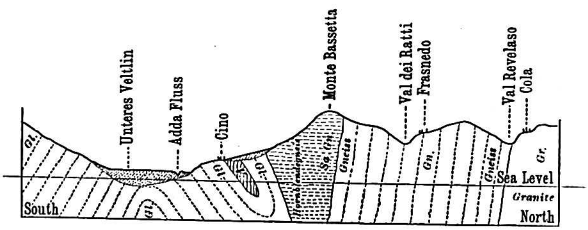


FIG. 148.—Profile through the Lower Val Tellina to Lola near Novate.

whole way from Craveggia in Piedmont, by Gravedona, to Cercino in the Val Tellina.

Some of the smaller lakes in these regions, as for instance those of Cadagno and Tremorgia, are "Meres" or lakes of sinking, like those of Cheshire.

The massif of Ticino is now cut through by a series of deep and wide valleys running like the Val Leventina from the north, southwards. These valleys owe their origin to the original slope of the ground, and must be of great age, dating back probably far into the Tertiary period.

Several of the Italian Lakes descend below the sea level. The Lago Maggiore is remarkable for its colossal depth, no less than 655 metres. It is in the main a transverse valley, and at the north and south ends the geological structure of the two sides agrees. The west bank between Arona and Baveno consists mainly of Crystalline Schists, while the east exhibits the whole series of subalpine strata, from the Cretaceous to the Verrucano.

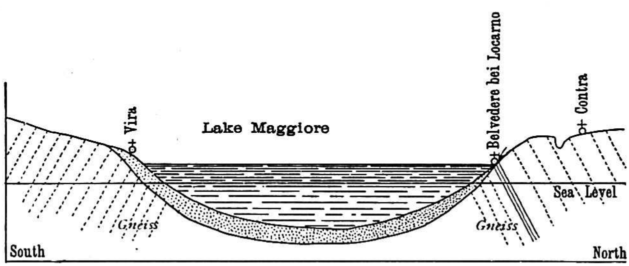


FIG. 149.—Profile across the Lago Maggiore in Val Verzasca.

The plain of the Po is probably due to subsidence. It is the lower part of the great fold of which the Alps form the upper arch, and must descend far below the sea level.

The alluvial deposits are of great, but unknown depth; at Milan a boring was sunk for 160 metres without reaching the bottom,[1] nor do we know on what strata the alluvium rests. The lakes therefore may be compared with the fiords of Norway or of Scotland; they are

[1] Bonney, *Alpine Journal*, 1888.

ancient river valleys, which have sunk far below the sea level.

It is probable that the plain of Lombardy was an arm of the sea during part of the Ice Age, for the manner in which the glacial deposits have been evenly spread over the plan can hardly be accounted for except by marine action. The hill of the Superga, near Turin, is miocene, bent into an anticlinal.[1]

Fig. 150 gives a section across the Ticino and Bernina Massives, from Weissberg in the north, to Dubino in the south.

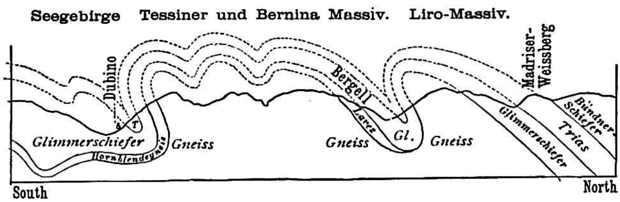


FIG. 150.—Ideal Profile from the Seegebirge across the Tessiner und Bernina Massif to the Liro-Massif.

The L. of Lugano owes its complex form to the fact that it consists of two longitudinal, and two transverse valleys dammed up by moraines.

It is remarkable that the Lago d'Orta differs from the other Italian lakes in having its outflow, not in the natural line of the drainage, viz. to the south, but on the contrary to the north. This is due to the southern end being closed by a moraine.

[1] Penck, *Morph. der. Erdoberfläche*, vol. ii.

CHAPTER XXIV

THE ENGADINE

THE Engadine, or valley of the Inn, from the Maloja, nearly to Kufstein, is a geotectonic valley. The upper portion can be followed down the Val Bregaglia, by Roveredo to Bellinzona, down the Ticino to Locarno, even beyond which it can be traced far into Piedmont.

The Upper Engadine is in the main a district of Gneiss, capped by Crystalline schists, interrupted here and there by Granite and with troughs of Sedimentary rocks, so much altered, however, by heat and pressure as to be almost unrecognisable, but suggesting that the whole district was once covered by fossiliferous strata.

Granite occupies a considerable district between Bevers and Piz d'Err (the Val Bevers being cut into it), both sides of the Julier road from the pass down to Silvaplana, a large tract south of Pontresina, and again the massif of the Monte della Disgracia.

The Bernina

The Bernina is not a comparatively simple central mass like that of Mont Blanc, where we find a compact crystalline nucleus with well-marked fan-structure. It is rather a complex mass of semi-detached bosses, which were long supposed to consist throughout of crystalline rocks; but more complete study has shown that these are only a mantle, covering a central mass of plutonic origin, and itself once covered by sedimentary deposits.

The so-called fan-structure can be traced, but is not well marked.[1]

The Bernina Pass itself has long attracted attention as having no true watershed. The flat summit is occupied by four small lakes, at a height of 2220 metres, which in wet weather often unite into a single sheet, from one end of which the water runs north to the Inn, and consequently to the Black Sea; from the other to the Poschiavina and the Adriatic.

The valley of Pontresina, according to Theobald, is (Fig. 151) a synclinal between two masses of Granite and Syenite.

The Inn is a river which has been deprived of its original source. In most cases as we pass up a stream to its origin we find the valley becoming gradually narrower and less deep,

[1] Theobald, *Beitr. z. Geol. K. d. Schw.*, L. iii.

until at last we arrive either at a mere rill on the side of a hill, or at a spring rising from a combe in the hillside, and finally at a ridge which forms the watershed. The Upper Engadine forms a remarkable exception. If we look upwards from Celerina towards the Maloja we see above us a broad valley, which would appear to indicate a great river, the source of which must be miles

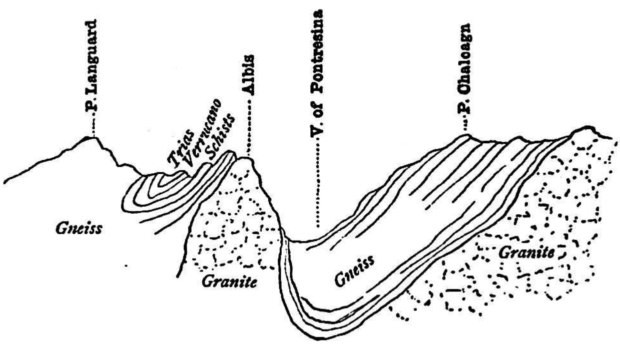


FIG. 151.—Section across the valley of Pontresina.

away. Instead of this we have a succession of lakes, threaded on a small stream, and when we arrive at the Maloja, the main valley, still broad and deep, suddenly ends, and we find ourselves on the brink of a steep descent into the Val Bregaglia. The Engadine is in fact a truncated valley, the so-called source of the Inn is in reality merely one of the tributaries of the old main river; and there is no Inn above the Lake of Sils, the sources of supply having been cut off. Nor is it only the main river which has disappeared, but several of the former tributary streams have been carried away into Italy.

"If," says Prof. Heim, to whom and to Prof. Bonney our knowledge of these facts is mainly due, "we imagine the valley southwards of the Maloja filled with cloud, over which we were looking to the clear heights above, we should see a series of valleys, the Val Marozzo, Val Albigna, so-called from the whiteness of the water, Val Muretto, etc., all converging towards the Inn, of which apparently they were undoubtedly tributaries. But the cloud lifts, and we see to our surprise that they open on the southern side of the watershed, and turn sharply down the Val Bregaglia."

The slope of the Val Bregaglia being much steeper than that of the Inn (Fig. 152), the river Maira has gradually cut its way back and appropriated more and more of the territory which originally belonged to the Inn. The waters of the Val Marozzo, now called the Upper Maira, and the Val Albigna were once tributaries of the original Upper Inn, but have been carried off into Italy by the victorious Maira. Hence the Upper Engadine at the Maloja is from the first a broad valley, because it represents part of the course of a stream which has lost its head waters.

Though the evidence is not so striking

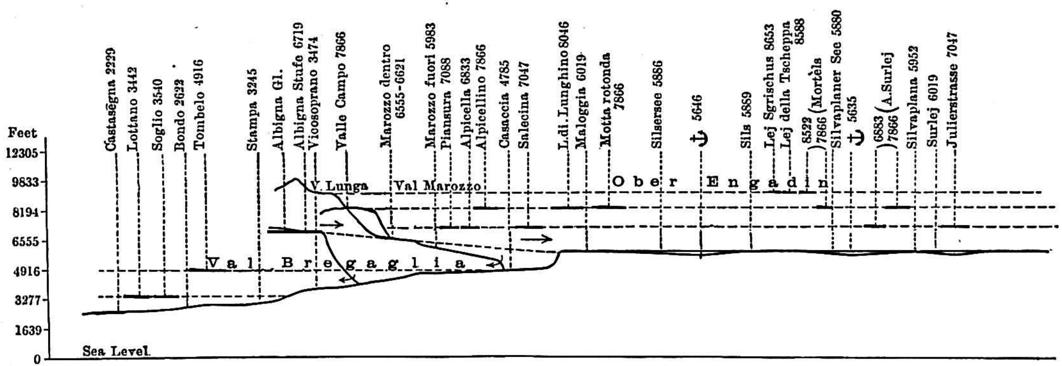


FIG. 152.—Profile of the Val Bregaglia and the valley of the Upper Inn.

we find a similar state of things on the Lukmanier, the St. Gotthard, the Cenis, in fact most of the great Alpine passes, and we may say with confidence that the watershed between Switzerland and Italy was formerly further south, and is gradually, though of course very slowly, retreating towards the north. Moreover, as already mentioned, the Nagelflue (Miocene) deposits of the great Swiss plain between the Alps and the Jura contain many pebbles which must have come from high mountain ranges to the south of the present watershed, being formed of rocks which do not occur in Switzerland, but are found in the Italian valleys.

Another result of the change has been the formation of the chain of lakes, St. Moritz, Campfer, Silvaplana, and Sils, which characterise the Upper Engadine. Under the former *régime* the flow of water down the main valley was sufficient to carry off the materials brought down by the lateral tributaries. But since the head waters have been cut off and carried away into Italy this is no longer the case; hence the lateral streams have built up dams across the valley, thus causing the chain of lakes.

The lake at Davos is probably due to a similar cause, the former head waters of the Landwasser having been captured by the Landquart. (See *ante*, p. 187).

The Val Bregaglia and the Upper Engadine constitute, as already mentioned, one great trough valley.

The west half of the Silser See and both sides of the Val Bregaglia as far as Nazarina are Talc Schists, much contorted. Isola stands on a river cone, formed by the stream of the Val Fedoz. The promontory opposite Isola is a ridge of Trias which runs south-west to the Piz Lunghino. Beyond it to the north is Serpentine; the north-east of the lake is Mica Schist, above which is Granite stretching from Piz Lungen to Piz Munteratsch, across which passes the Julier Road. It consists of white or pinkish Orthoclase, green Oligoclase, gray or white Quartz and brown Magnesia, and Mica. These tints make it one of the most beautiful rocks in the Alps. The grains are of medium size. It crosses the valley and extends to Pontresina. Both the Val Roseg, and that of Morteratsch are excavated in it, and it forms a great part of the Bernina mountains, though the actual summit is Syenite-Diorite.[1]

The Lake of Silvaplana was no doubt once continuous with that of Sils. The flat ground on which Sils stands is alluvium brought down by the stream from the Val Fex. On the left side are Triassic strata, the continuation of those already mentioned, and beyond them

[1] Theobald, *Beitr. z. Geol. K. d. Schw.*, L. iii.

on the left of the lake is Serpentine. On both sides of the Lake Campfer is Granite, and at the lower end Casanna Schist.

Fig. 153 shows that, as already mentioned, the valley of the Upper Inn is a trough.

When we pass from the Granite of the Julier to that of Pontresina and the Rosatch

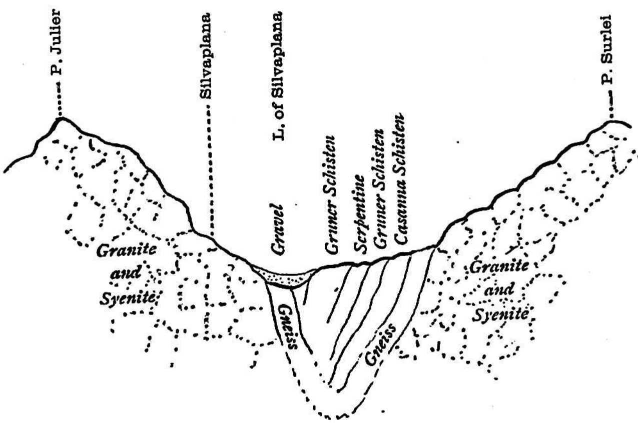


FIG. 153.—Section across the valley of the Inn from P. Julier to G. Surlei.

we might at first suppose that the two banks of the Inn were in direct connection. This is however not so, but from Maloja to Scanfs the Inn runs in a trough of Schistose rocks, which separate the Julier from the outposts of the Bernina. They are principally Casanna Schists.

The Lake of St. Moritz has Syenite on the west, Gneiss on the north, and Mica Schist on the south. At Celerina we come on the wide stretch of the Upper Inn which stretches to Scanfs. At Bevers is the opening of the wild valley of that name which is excavated entirely in Granite. The herbage is excellent and the flora very rich, but the valley is uninhabited in winter. It is almost inaccessible except at the entrance, the mountains surrounding it being extremely steep.

During the Glacial period the great glacier coming down from Pontresina probably blocked up the main valley to so great a height that those of the upper district from the Julier Alp, Val Fex, Val Fedoz, etc., were driven over to Maloja and down the Val Bregaglia. Near Celerina is a mass of rock on which the church of St. Gian stands; it is a quarter of a mile long, and one-eighth of a mile broad, and 150 feet high, rounded at the upper end and precipitous on the north-east towards the lower valley, showing that the ice flow was in the direction of the Inn. On the other hand, at Sils Maria is a similar mass of rock, with the slope towards the north-east and the precipitous side on the south-west, showing that the ice-flow was in the opposite direction. The ice-shed therefore must have been somewhere near Campfer. Just in front of the great Maloja Hotel are some beautiful specimens of Gneiss rocks moutonnées.

The glacier reached a height of over 8000 feet, below which the rocks are rounded and smooth, while higher up they are rough and jagged.[1]

At Cinuskel the river diverges somewhat to the north of the line of sedimentary rocks, skirting them on the left, and for some distance has crystalline rocks on both banks. The reason of this is not obvious, but we must remember that the denudation has been immense, and the deflection is probably due to some cause connected with the strata which have been removed. At any rate from Cinuskel to Guarda the sedimentary strata have been entirely removed on both sides of the river, which flows over crystalline rock.

At Zernetz the great crystalline boss of the Monte Baselgia forces the river to make a wide curve, after which it resumes its previous course. On the west side of the mountain the lateral streams join the Inn almost like the spokes of a wheel on some gigantic axle—the Ova Sparsa, Sursura, Susasca, Sagliano, Lavinuoz, and Tuoi. On the other hand, the original line of the valley, as indicated by the strata, passes in a straighter line to the south-east of the mountain.

The mountain itself consists of Gneiss and Crystalline—principally Hornblende—Schist. In the centre of the boss the strata are

[1] Theobald, *Beitr. z. Geol. K. d. Schw.*, B. iii.

perpendicular, with gaping fissures of great depth.

The small plateau of Ardez is one of the most interesting parts of the Lower Engadine. The basis is Granite, which resembles that of the Julier, and in many places comes to the surface. It is often polished, doubtless by glacial action.

Fig. 154, representing a section of the Inn

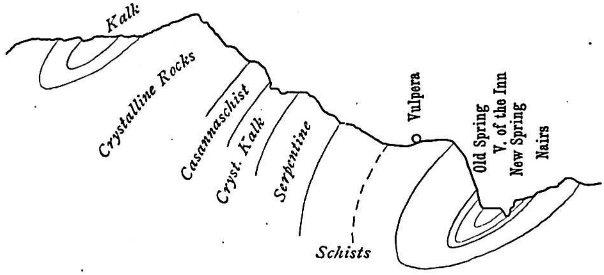


FIG. 154.—Section across the valley of the Inn at Tarasp.

Valley at Tarasp, shows that the strata are overthrown into compressed folds and the river runs in a synclinal trough.[1]

From Ardez to Remus the river runs between Lias on the left, and (Haupt-Dolomite) Trias on the right, along a line of disturbance through which Granite, Gneiss, Serpentine, and other Plutonic rocks come to the surface.

The Liassic rocks of this district fall into undulations, the principal of which is the deep trough which has on the whole deter-

[1] Theobald, *Beitr. z. Geol. K. d. Schw.*, L. ii.

mined the course of the Inn, and has also given rise to the mineral springs at Tarasp and Schuls. These are perhaps due to a fracture along the line of the valley. The temperature of the water is not hot nor constant, which indicates that they do not come from any very great depth.

From a little below Remus to Prutz the river has Liassic rocks on both banks, which below Martinsbruck takes the form of clay-slate, and through which the deep magnificent gorge of Finstermünz is cut to a depth of 1000 metres.

Speaking of the lower course of the Inn below Landeck, Bonney says, "Of a valley of strike the course of the Inn from Landeck to below Jenbach is an excellent example. The river flows roughly from west to east for full 50 miles, bounded on the south by the central range of Crystalline rock, on the north by the overlying limestones and shales of the secondary series. It receives the drainage of many considerable lateral valleys from the former, of sundry glens from the latter. The junction of two great rock groups, differing so markedly in their powers of resistance, has obviously determined the initial course of the river valley, which broadens as the stream descends from a height of 2750 feet to about 1700 feet."[1]

[1] 109. Bonney's "Growth and Sculpture of the Alps" in *Tyndall Lectures.* Roy. Inst., 1888.

CHAPTER XXV

GENERAL SUMMARY

In the preceding chapters I have endeavoured to trace the causes which have led to the present scenery of Switzerland.

In Permian times there were probably mountains where the Alps now rise, but this ancient range was gradually removed by denudation; moreover the land sank, and during the Permian, Liassic, Jurassic, and Cretaceous periods there was deep sea where the Alps now rise. There were certainly great changes of level, but they were all continental, and that is to say they were approximately the same for the whole area, there was no compression and no folding.

That the sea during this period must have covered the site of the present Alps is proved (1) by the fact that we find no trace of its southern shores, no littoral deposits. If the Alps had then existed, pebbles, etc., from them must have been found in the Liassic, Jurassic, and the Cretaceous rocks. This is not the case: indeed these rocks contain no pebbles of any kind, and the fossils in them are all indicative of deep water far away from land. There are no conglomerates or gravel beds between the Permian and the Upper Eocene. Again (2) we find remains of the Secondary strata protected in the troughs of the folds. These sedimentary deposits therefore extended completely over the site of the present mountains, and though no extensive remains of these deposits now occur in the Central Alps, this is because they have been entirely stripped away.

The elevation of the country was due, not to upheaval from below, but to lateral pressure owing to the cooling and consequent contraction of the earth. It has been calculated that the strata between Basle and Milan, a distance of about 130 miles, would, if extended horizontally, occupy 200. There has consequently been a shortening of no less than 70 miles.

For some time the central ranges alone were above the water, and the mountain torrents brought down gravel and boulders, forming the "Nagelflue" of the Rigi and the Central Plain.

The Alps therefore, from a geological point of view, are very recent. Our Welsh hills, though comparatively speaking insignificant, are far more ancient. They had been mountains for ages and ages before the materials which now compose the Rigi or the Pilatus were deposited at the bottom of the sea. Indeed, we may say that it is because they are so old that they have been so much worn down: the Alps themselves are crumbling, and being washed away; and if no fresh elevation takes place, the time will come when they will be no loftier than Snowdon or Helvellyn.

They have already undergone enormous denudation, and it has been shown that from the summit of Mont Blanc some 10 to 12,000 feet of strata have been already removed. The conglomerates of Central Switzerland, the gravels and sands of the Rhine and the Rhone, the Danube and the Po, the plains of the Dobrudscha, of Lombardy, of South France, of Belgium and Holland, once formed the summits of Swiss mountains. This amount of denudation gives us, I will not say a measure, but at any rate a vivid idea of the immense time that must have elapsed since the Alps rose out of the sea.

Denudation began as soon as the land rose above the sea, and the main river valleys were excavated. Then came a period of cold known as the Ice Age or Glacial period.

Round all the high mountains, and over many of them, are great fields of ice and snow, terminating in glaciers. These, however, are but the remnants of a much larger sea of ice which once covered almost the whole country. The glacier of the Rhone for instance descended the Valais, filled the Lake of Geneva, rose to, what is now, a height of 1350 metres on the Jura, and then dividing, sent one branch as far as Lyons, and a second along the Aar to Waldshut. The Glacial period, however, was not continuous, but interrupted by at least two periods of more genial climate. The mass of material brought down from the mountains partially filled the river valleys (which have not even yet been entirely re-excavated), formed great moraines, and is spread in thick, but irregular, masses over all the lower ground.

The rivers of Switzerland run mainly in one of two directions, the first from south-west to north-east, or *vice versa*, following the strike and original folds of the strata, and the second at right angles to it. Many, indeed most, of the principal rivers, take first the one and then the other direction in different parts of their course. In some cases the rivers cut through mountain ranges, as for instance the Rhone between Martigny and the Lake of Geneva. This probably indicates that the river is older than the mountain range, and cut through it as it rose.

The river system of Switzerland was, however, at first very different from the present. The Vosges and the Black Forest were continuous, the subsidence which now separates them not having yet taken place, so that the Rhine Valley at Basle was not in existence.

Nor had the gorges by which the Rhone finds its exit through the Vuache yet been formed, and the consequence was that the whole drainage of Switzerland north of the Alps found its way by the Danube to the Black Sea. For some time after the subsidence of the Basle Valley had taken place the upper waters of the Rhone still joined the Rhine, and ran over the plains of Germany to the North Sea; finally, however, it broke its way by the Fort de L' Ecluse, and falling into the Saône, runs to the Mediterranean. Another general change in the river system is that the crest of the Alps has retreated northwards. The southern slope being much steeper than that to the north, the Italian rivers have more power of erosion than their northern rivals, and are gradually eating their way back. The Upper Engadine is a conspicuous example.

Many minor changes have taken place: partly (1) through recent changes of level, as for instance that which has diverted the Reuss from its old course by the Lake of Zug, and driven it round by Lucerne; partly (2) by rival rivers deepening and extending their valleys, and thus annexing territory which previously belonged to others: for instance, the Landquart has robbed the Landwasser of its head waters and carried off the Schlappina, the Vereina, and the Sardasca; partly (3) by dams due to river cones or glacial moraines, as for instance the Limmat, which was driven from the Glatthal and the Sihl from the valley of the Lake of Zurich.

The lakes which contribute so much to the beauty of the country fall into several different categories.

1. Some are due to the inequalities in the glacial deposits; as the numerous small pieces of water in the curious district of the Pays de Dombes.
2. Some are due to subsidence; strata, generally those of gypsum or salt, having been dissolved and removed; as for instance the Lakes of Cadagno and Tremorgia.
3. Some are dammed back by river cones, as the lakes of the Upper Engadine; or by moraines, as the lakes of Sempach, Baldegger and Hallwyl.
4. The origin of the larger Swiss lakes has been the subject of much discussion. The opinion now prevalent among Swiss geologists is that they are mainly due

to recent changes in level, and are in fact drowned river valleys.

Even more striking than the exquisite beauty of the lakes is the grandeur of the history they unfold, and of the causes to which they are due; and indeed, in contemplating the general Scenery of Switzerland, we cannot but be profoundly impressed by the enormous magnitude of the changes, and the irresistible forces which have been brought into operation.

Those forces have affected the general configuration of the Earth's surface. Attention has often been called to the fact that so many great masses of land point southwards—South America, Africa, India, etc.

Many of the peninsulas, moreover, have an island, or group of islands, at their extremity, as South America, which is terminated by the group of Tierra del Fuego; India has Ceylon; Malacca has Sumatra and Borneo; the southern extremity of Australia ends in Tasmania or Van Diemen's Land; a chain of islands runs from the end of the peninsula of Aliaska; Greenland has a group of islands at its extremity; and Sicily lies close to the southern termination of Italy.

Some years ago I ventured to suggest[1] that we might correlate this with the remark-

[1] *Nature*, 1877. See also a paper in the *Journ. Roy. Geogr. Soc.*, 1895.

able preponderance of ocean in the southern hemisphere, which M. Adhémar has suggested to be due to the alteration of the centre of gravity of the Earth, caused by the great southern cupola of ice.

However that may be, the preponderance of water in the south is very remarkable. Taking each parallel as unity, the proportion of sea is as follows:—

60 North	0,392	10 South	0,795
50 ,,	0,438	20 ,,	0,763
40 ,,	0,538	30 ,,	0,797
30 ,,	0,567	40 ,,	0,961
20 ,,	0,574	50 ,,	0,983
10 ,,	0,758	60 ,,	1,000
0 ,,	0,783		

Without at the present moment entering upon any discussion as to the cause which has produced this remarkable result, the fact at any rate seems to throw some light on the southern direction of promontories. For let us suppose three tracts of land, each trending north and south, each with a central backbone, but one with a general slope southwards, one with a northward slope, and the third without any. The first will, of course, form a peninsula pointing southwards, because, as we proceed southwards, less and less of the surface will project above the water, until nothing but the central ridge remains. The second tract, however, would also assume the same form, because, though by the hypothesis the land does not sink, still, the gradual preponderance of water would produce the same effect.

If, moreover, the central mountain ridge, as is so generally the case, presents a series of detached summits, the last of such elevations which rises above the water level will necessarily form an island. This suggests a possible reason why Africa, unlike the other south-pointing lands, has no island at its extremity. They are folded ranges. The Cape of Good Hope, on the contrary, is a table mountain, bounded by two converging areas of subsidence which meet at Capetown.

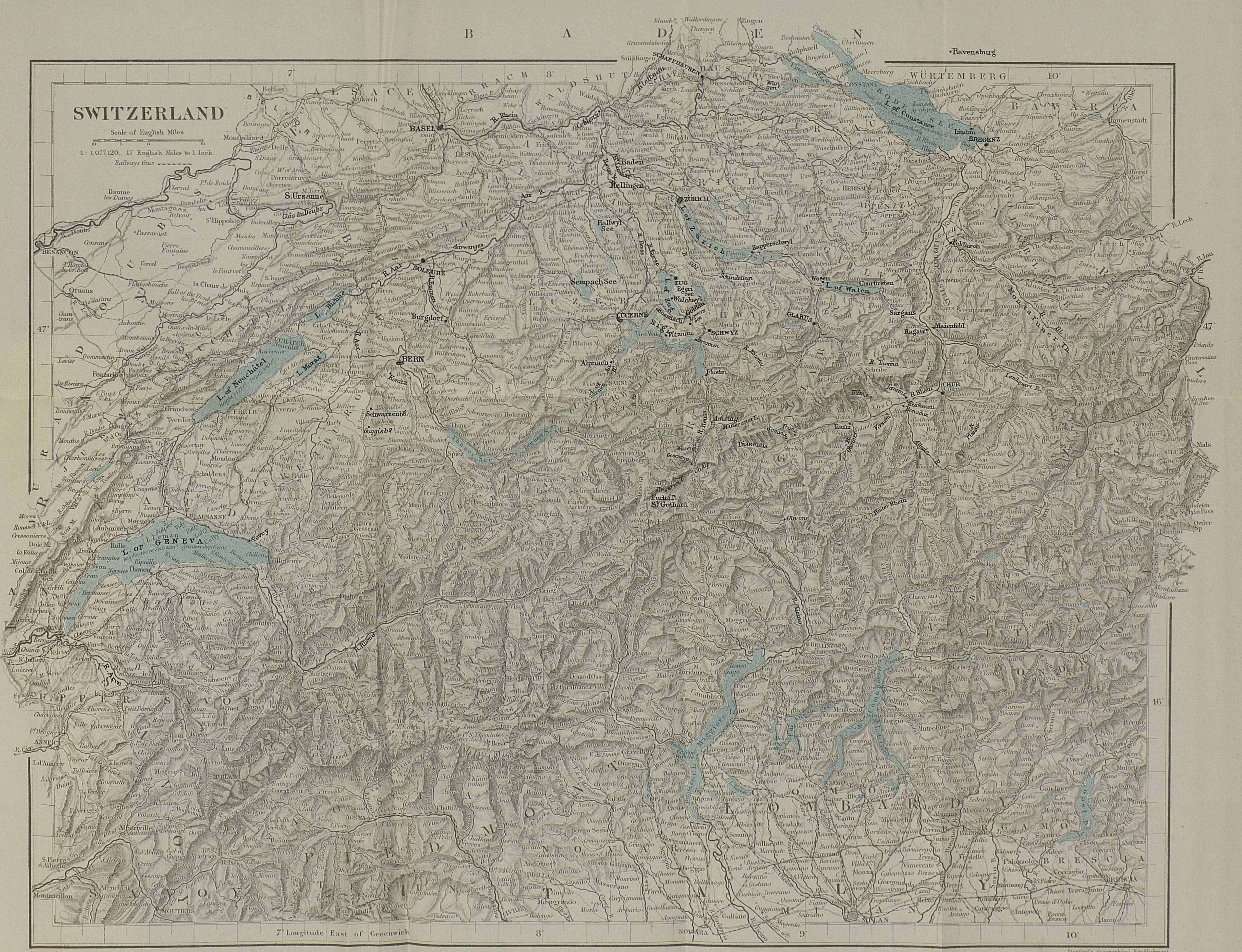
Lastly, in the third case, the gradual diminution of water would tend to neutralise the effect of the slope, and if the two were equal, the land would form—not a pointed peninsula, but an oblong tract.

So far as I am aware, no notice has been taken of this suggestion except by Prof. Penck, who characterised it as self-evident. However this may be it had not been previously pointed out, and indeed an objection, to which for long I saw no answer, was suggested to me by Mr. Francis Galton. He urged that no accumulation of water in the northern hemisphere would give promontories pointing to the north. I tried various hypothetical enlargements of the northern seas, but in vain. The explanation lies, I think, in the necessary equivalence of the great folds on the Earth's surface.

If folded mountains are due, as above suggested, to a diminution of the diameter of the Earth, every great circle must have participated equally in the contraction. The east and west folds would on the whole counterbalance to those from north to south. This must be so theoretically, but we have no means of testing it by exact figures. It is interesting, however, to observe that while the mountain chains of the Old World run approximately from east to west, those of America are in the main north and south. Speaking roughly, the one series would seem to balance the other, and we thus get a clue to the remarkable contrast presented by the two hemispheres. Again, in the northern hemisphere we have chains of mountains running east and west—the Pyrenees, Alps, Carpathians, Himalayas, etc.—while in the southern hemisphere the great chains run north to south—the Andes, the African ridge, and the grand boss which forms Australia and Tasmania.

This, then, seems to me the answer to the difficulty suggested by Mr. Galton. The mountains in the southern hemisphere running north and south give us when combined with the preponderance of water the southern pointing promontories. No such preponderance, however, in the northern hemisphere would give us northern pointing promontories, because there the great folds run not from north to south, but from east to west.

Thus, then, the explanation of great mountain ridges by lateral pressure and consequent folding, coupled with the necessity of approximately equivalent contraction along every great circle, explains the balance of east and west and north to south chains in each hemisphere, and this again, in conjunction with the preponderance of water in the south, explains the tendency of land masses to taper southwards, and end with an island or group of islands, thus throwing an interesting light on some of the principal features in the configuration of the Earth's surface.



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Stanford's Geographical Establishment.

APPENDIX

LIST OF WORKS AND MEMOIRS REFERRED TO

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„ 18. Vaud, Fribourg, and Berne. By V. Gilliéron, 1885.
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